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PSYCHOLOGICAL AND PHYSIOLOGICAL CONSEQUENCES OF DRIVING STRESS

Final Report

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16. Abstract

This project consisted of a review of the literature in subject areas related to driving stress, aging, and health. This document contains:

1. A comprehensive review of the literature concerning the impact of driving on the health, behavior, and subjective well-being of drivers.

2. A comprehensive review of the literature on the cognitive and perceptual consequences of aging that is relevant to driving tasks and driving stress.

3. The identification of personality and lifestyle dimensions which contribute to driver susceptibility to stress.

Recommendations for research in each of these subject areas is suggested.

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I. Driving Stress: A Review of the Literature

INTRODUCTION

In recent years behavioral scientists have extensively researched the impact of the urban environment on the physical health and the subjective well being of residents. A sizable body of literature now exists which documents potentially harmful consequences of such urban variables as population size, population density, ambient noise, air quality, and residential design. This research falls under the heading of "urban stressors" and is used by urban planners and architects to guide planning and design decisions. Despite the recent profusion of research in this area, certain aspects of the urban environment have received relatively little empirical attention.

Among the most important of these neglected topics concerns the effect of driving conditions on the health and well being of drivers and their passengers. An adequate understanding of these factors is vital when we consider that the automobile is a central part of the daily life of most urban and suburban residents, as well as the primary mode of transportation for nearly 90% of the U.S. labor force (Novaco, Stokols, and Milanesi, 1990). In addition, in major metropolitan areas the proportion of automobile commuters ranges from 85% to 93%. With increasing traffic congestion in such areas, commutes are becoming longer, more demanding, and more stressful. In one study of transportation related problems (Quinn & Staines, 1979), 33% of the respondents characterized their driving problems as "sizable" or "great." In another study (Turner, Layton, & Simons, 1975), 12% of the men and 18% of the women sampled reported that at times, they "could gladly kill another driver."

These startling figures indicate the substantial role that driving plays in the daily lives of modern Americans. As greater numbers of people come to rely on automobile transportation, driving conditions are becoming more congested. This means that daily commutes become longer and more difficult, placing increasing demands on the individual driver. A partial resolution to these problems involves the development and implementation of IVHS (Intelligent Vehicle-Highway System). Early developments will include driver information advisory services, a prototype of an ADIS (Advanced Driver Information System), as well as traffic control mechanisms such as freeway ramp metering. However, because automobile travel is such an integral part of modern life, understanding how current and future driving stressors affect the individual is an important concern.

Specifically, it is important to evaluate the impact of road design and traffic variables on levels of "driver stress." Driver stress is a term which refers to the cumulative negative physiological, psychological and behavioral reactions which occur as a consequence of driving. These reactions, while sometimes less immediate and less visible than monetary and time losses, should nevertheless be considered during the design of a transportation system. Some such consequences are thought to include accident rate, short and long term health problems, and driver conflict.

This paper discusses the existing literature relating to driver stress and its physiological and psychological effects. However, before specifically discussing stress in the driving situation, it is necessary to discuss different ways of conceptualizing stress as a general phenomenon.

STRESS MODELS

The concept of "stress," as it applies to human beings, is <u>polysemic</u>; it refers to a diverse set of concepts and phenomena. The term itself originated in the field of engineering, where it refers to a measure of force per unit area. The resulting temporary or permanent change in the structure of the object is termed "strain." In this usage, the distinction between the external forces and their effect is quite clear. However, when the word "stress" is applied to human beings, the distinction quickly becomes blurred. Humans, in contrast to physical objects, are not passive elements within their environmental system. Rather, people actively perceive, interact with, and alter their surroundings. To be useful in this context, a model of stress must encompass a number of different aspects, including external stimuli, the individual's perceptions, physiological and psychological responses, and coping mechanisms. Further, the model must explain how these elements interact with each other to form an adaptable system. Historically, theories of stress have not emphasized such an integrated viewpoint. Cox (1978) describes three approaches that previous researchers have used in defining stress: response-based, stimulus-based, and interactional models.

Response-Based Stress Models

Response-based approaches to studying stress place considerable emphasis on the individual's response to disturbing environmental features. The primary focus of attention is on specifying the particular pattern of physiological or behavioral changes which may be taken as evidence that an individual is, in fact, under pressure from an external source.

This approach to stress was first proposed by Hans Selye (1956). Selye noted that a number of different kinds of environmental stressors produced a similar pattern of physiological responses. These responses represented the organism's preparation for defense. Selye believed that the nature of the stress response was essentially identical regardless of the type of stressor or even, within reason, the species of the organism. He called this common pattern of physiological reactions the General Adaptation Syndrome. With continued exposure to the stressor, the stress response proceeds through three identifiable stages: alarm, resistance, and exhaustion. The alarm phase involves the initial "fight or flight" reaction, in which the organism prepares itself physiologically for the activity that will be necessary for survival. This state of physiological arousal cannot be maintained indefinitely, and if exposure to the stressor is continued, the organism will enter the resistance phase. In this phase, the organism adapts to the stressor, and many of the physiological changes associated with the alarm reaction are reduced. Further prolonged exposure to the stressor may lead to the exhaustion phase, in which the organism's ability to adapt to the stressor is lost, and the organism may collapse and/or die.

One weakness of this sort of approach to studying stress is that classifying any stimulus that produces a typical "stress response" pattern of physiological changes as a stressor may lead to including conditions that are not experienced as particularly stressful, such as passion, exercise, and surprise, under our definition of stress inducing situations (McGrath, 1970). Another important weakness of response-based approaches is the fact that there are considerable individual differences in responses to stress. Two people presented with the same noxious stimulus do not react identically. One may experience a sharp rise in heart rate while the other does not. Moreover, a single person presented with the same stimulus on two different occasions may react differently each time. Also, all symptoms of the "syndrome" do not always appear together. The problem inherent in response-based definitions of stress, then, is the lack of a consistent correspondence between the external stressor and the individual's immediate internal state. These approaches leave no room for response variability, and such variability, in fact, is frequently reported in studies of individuals in "stressful" situations.

Stimulus-Based Stress Models

Stimulus-based approaches to stress describe the concept in terms of the characteristics of environments that are considered stressful. Stress is conceptualized in terms of external forces present in the environment that may act upon the individual, a usage very closely related to the original engineering terminology. The emphasis in this framework is to enumerate the conditions that can be accepted as stressors. These include excessive information processing demand, noxious environmental stimuli, perceived threat, disrupted physiological function, isolation, group pressure, and frustration.

The main problem with such an approach again lies in the area of individual differences. A high demand situation, for example, may be stressful for most, but not all, people. Stimulus-based stress models cannot account for these variations in what different individuals find stress inducing. Also, this type of framework tends to encourage the development of a number of different stress theories that each cover only one distinct class of stimulus conditions, leading to a fragmented, and relatively impoverished, understanding of the stress phenomenon (McGrath, 1970).

Transactional Stress Models

The third approach to conceptualizing stress combines aspects of the response-based and stimulus-based definitions with an emphasis on the perceptions and interpretations of the individual. Cox suggests that stress can be most adequately described as "part of a dynamic system of transaction between the person and his environment." Such transactional or interactional models (e.g., Cox, 1978; McGrath, 1976; Lazarus, 1966) place a good deal of importance on the perceptual-cognitive processes of the individual. Human beings are not purely objective evaluators of their environments. Each person has his or her own unique perspective which colors the interpretation of reality. People differ in personality and have different histories. Any given environmental feature is not experienced identically by any two people. Moreover, individuals' abilities to cope with the environment, and their own perceptions of these abilities, also differ. With such variation in perceptions and abilities, it is not surprising to discover significant individual differences in stress responses.

The crucial element in transactional theories is a cognitive appraisal process (Lazarus, 1966). The basic idea of cognitive appraisal is that the stress inducing qualities of an event are dependent on the individual's perception and interpretation of that event. Thus different people in the same situation may experience it very differently. One way of conceptualizing this process is to view cognitive appraisal as a point at which an individual compares his perceptions of environmental demand with his perceptions of his abilities to cope. Environmental demand can produce stress only when the individual anticipates that he or she will be unable to adequately cope with it without endangering other goals. Stress will arise when there is a "mismatch" or "imbalance" between the perceptions of situational demand and coping ability. Figure 1 (from Cox, 1978) shows how cognitive appraisal plays a key role in a transactional model of stress.

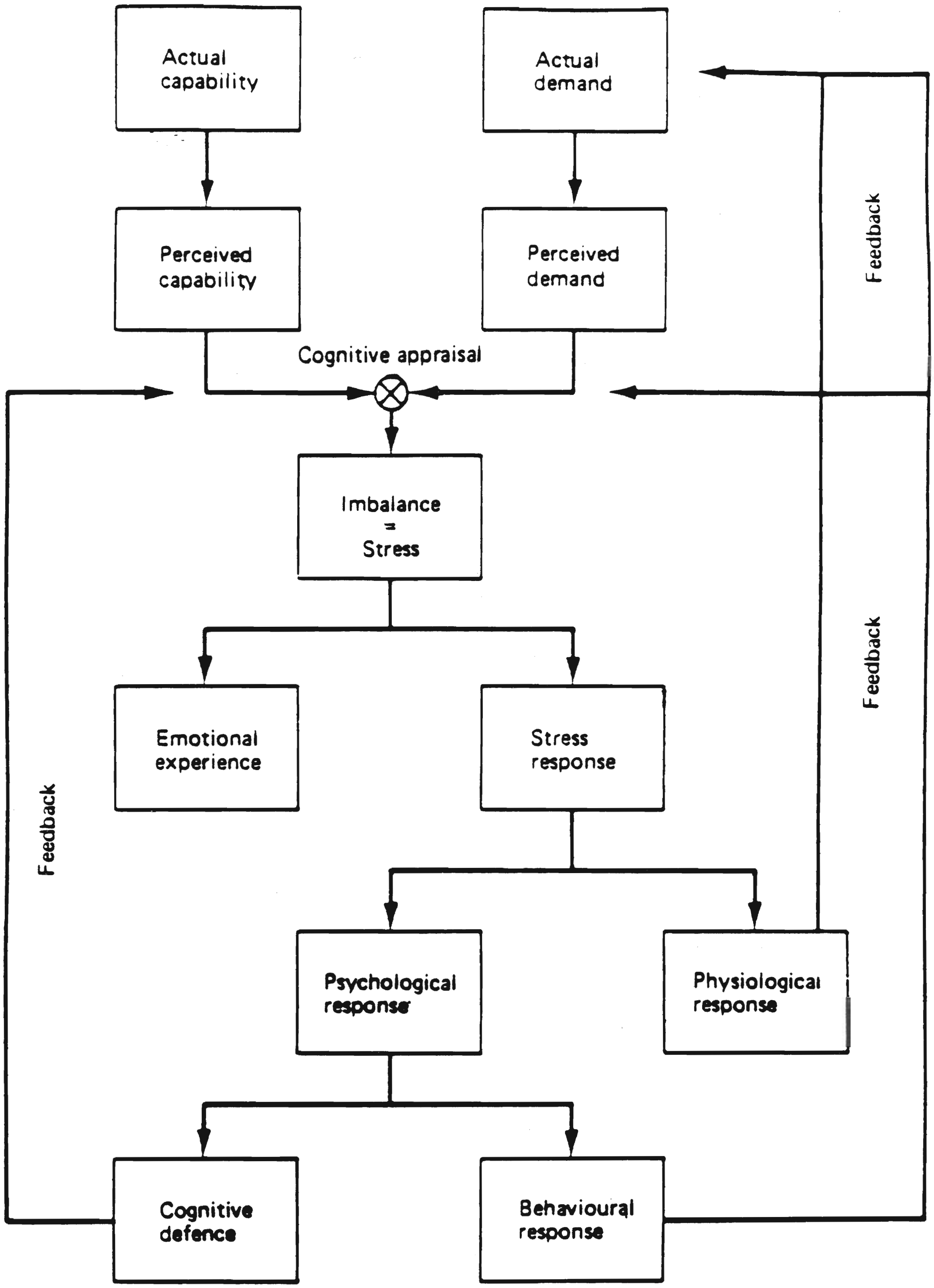

Figure 1. A transactional model of stress (Cox, 1978).

Every situation places demands on the individual. These are represented by the "actual demand" box in the model. These demands may include physical, attentional, or information processing requirements of the external situation, or they may be internally generated by the individual's physiological or psychological needs. However, the individual does not objectively assess the level of demand present in a given situation, but, instead, he or she views the situational demands through the filter of prior experience, with the result that the "perceived demand" in any given situation is unique to each individual experiencing it.

Each individual has a certain ability to adapt to the situation, based on his or her physical, mental, emotional, and behavioral capabilities. However, these abilities are not perceived objectively, but are also viewed through the filter of prior experience and personal belief. These actual and perceived abilities are represented by the "actual capability" and "perceived capability" boxes in the upper left of the model. The next step involves a comparison of the levels of perceived demand and perceived capability.

If, at this point, perceived capability falls below perceived demand, stress will result. It is important to remember that this comparison step involves perceived, rather than actual, levels of capability and demand. According to this model, a person whose actual level of capability is, in fact, insufficient to deal with the situation that he confronts but who has evaluated his abilities as adequate will not experience stress until such a point that feedback from the environment (lack of successful change) causes him to reevaluate his coping abilities and reappraise the demand-capability comparison as imbalanced and stressful. Similarly, a person who underestimates his or her own abilities will experience stress in a situation that he or she could, in fact, handle effectively. The operation of these perceptual processes, then, allows for a wide range of individual differences in stress responses.

When a given individual does experience stress, it involves both an emotional experience and a specific stress response. These two processes are not as easily separable as the model would suggest. The distinction is made, however, to emphasize the differences between the subjective experience of stress and its more objectively quantifiable physiological and psychological effects. The next stages of the model involve cognitive and behavioral attempts to cope with the stressor. If such responses are successful, the event is reevaluated as non-stressful and further coping behaviors are unnecessary. This benign reappraisal may be the result of cognitive restructuring or an objective change in the environment caused by an overt behavioral coping response. If reappraisal processes still indicate an imbalance, the individual continues to experience stress and continues to make attempts at coping.

The overall form of the model is a continuous loop, and this form is important in that it emphasizes the interaction between individual and environment. This process is even clearer in the simplified transactional model provided by McGrath (1976). This model is shown in Figure 2 below.

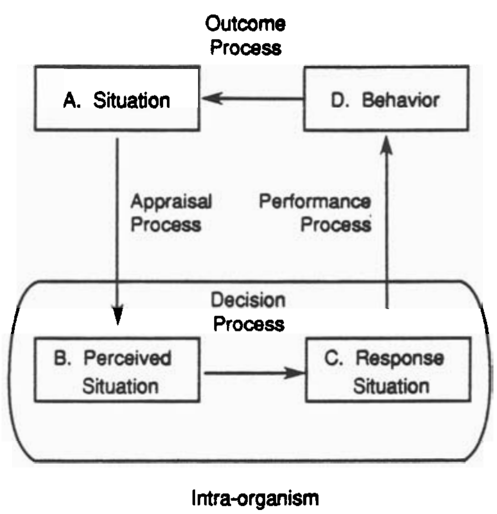

Figure 2. A simplified transactional model (McGrath, 1976).

It indicates that a situation (A), is appraised by the individual, resulting in a perceived situation (B). This is then used as the basis for a decision (C), which is carried out with certain behavioral responses (D). This behavior has an impact on the situation, which is then reappraised, beginning another cycle.

In the Cox model, the loop involves several different feedback mechanisms (cognitive, physiological, and behavioral) and is slightly more complicated than the McGrath model, but the same sort of reasoning applies. Feedback from any system can be sufficient to allow reappraisal of the person-environment interaction, which may, but need not, then be considered non-stressful.

TYPES OF STRESSORS

Two very different types of stressors have been investigated by researchers concerned with the effects of stress on humans. One line of research involves the effects of major life events on the health and well being of the individuals who experience them. Holmes and Rahe (1976) have developed an instrument to measure the number of stressful life events than an individual has experienced, and these are weighted according to the severity of the change. Events such as death of a spouse, divorce, marriage, retirement, pregnancy, and change in employment are included on this scale. Relationships have been found between the number of stressful life events and a variety of physical and psychiatric disorders. The attention of other researchers has centered on the relatively minor hassles that individuals encounter in the course of their everyday activities rather than on major life changes. Events such as losing a wallet and arguing with a teenage child may be placed in this category. The number of such events that an individual experiences is also correlated with physical and psychological health, and, in fact, the relationship is stronger for these daily hassles than for major life events.

The stress induced by driving may be classified as a daily hassle. Since driving is a very frequently and regularly encountered stressor, it is important to be able to understand the effects that driving has upon the health and well being of driver, and to be able to specify features of the driving system that may be modified to reduce this negative impact.

Driving Stress

The stress involved in driving is not attributable to any single source. Rather there are several aspects of driving that may each contribute to the experience of driving stress (Robertson, 1988). The driving task, the set of operations that are required to keep a vehicle on the road and avoid accidents, is only one potentially stress inducing aspect of the driving situation. The transport task, with the goal of getting from point A to point B within a certain period of time, is another potential stressor. Additionally, the environment inside the vehicle and the external environment can greatly affect the level of stress experienced by the driver. Selye (1976) echoes this point, stating that the "stressor potentiality" of driving is due to a combination of concentration, anxiety, physical discomfort of maintaining the same position for an extended period of time, boredom, vehicle vibration, noise, and many other possible factors. Robertson (1988) reports a commuting stress study by Costa et al. (1983) that found that the discomforts experienced by automobile drivers included such diverse concerns as the fear of being late (reported by 14% of the drivers in their sample) and the fear of being involved in an accident (reported by 61%).

Even within the driving task, there may be several different factors which contribute to the experience of driving stress. Gulian et al. (1989) and Synodinos and Papacostas (1985) have conducted factor analyses that indicate the existence of several different dimensions within the general concept of driving stress. Gulian et al. adopt a transactional approach to driver stress and conceptualize it as a set of responses associated with the perception and evaluation of driving as demanding and dangerous, relative to the individual's driving abilities. They suggest that driving stress might be experienced on two different levels. Specific events which tax the driver's ability may produce immediate, situational-level stress. Additionally, long-term repeated exposure to such events may have cumulative physical and psychological effects. It is emphasized that a number of factors extrinsic to the driving situation, such as the quality of one's family life and employment situation, may interact with driving stress if these influences affect driver's appraisal of road incidents.

Gulian et al. have developed an instrument to measure driving stress. The Driving Behavior Inventory (DBI) includes 97 questions about demographics; car use; accident history; health, personal, occupational, and domestic problems; mood, emotions, and attitudes toward driving, traffic situations, and road users; and coping strategies and behavioral responses to general and specific traffic situations. Respondents are asked such questions as "When in a hurry do you tend to drive near the car in front of you?" and "Would you say that other drivers drive too fast?".

Factor analyses of the DBI show two possible factor structures, with one and five factors respectively. This indicates that, depending on the specific type of analysis performed, the DBI is either measuring a singular construct or a combination of five different constructs. Eighteen of the 33 items designed to highlight driver stress reactions load >.40 on the single factor in the simpler solution. The five factor solution is as follows:

	Factor	% Variance
I.	Driving Aggression	15.5%
II.	Irritation When Overtaken	7.6%

III. Driving Alertness 6.4%

IV. Driving Dislike 5.0%

V. Frustration When Failing to Overtake 3.7%

This solution suggests that driver stress may be made up of a combination of five different dimensions (driving aggression, irritation when overtaken, driving alertness, driving dislike, and frustration when failing to overtake), each of which contributes uniquely to the level of stress experienced by any given driver. A replication of the analysis with a second sample provided similar results. The two possible factor structures found in the second study, and a list of the questionnaire items that make up each factor can be found in Figure 3.

Items	Loading
'Driving Aggression': Contribution to Total Variance: 14·1%	
Driving usually makes me feel aggressive	0·60
I tend to overtake other vehicles whenever possible	0·57
When irritated I drive aggressively	0·48
When I try but fail to overtake I am usually frustrated	0·48
Driving a car gives me a sense of power	0·46
I think it is worthwhile taking risks on the road	0·42
'Dislike of driving and related anxiety': Contribution to Total Variance: 6·9%	
I am worried to drive in bad weather	0·58
I am always ready to react to other drivers' unexpected manoeuvres	0·56
Driving usually does not make me happy	0·53
In general I do not enjoy driving	0·52
Driving usually makes me feel frustrated	0·48
I feel confident in my ability to avoid an accident	0·48
I am more anxious then usual in heavy traffic	0·48
I am more tense on new than familiar roads	0·47
I am usually patient during the rush hour	0·42
'Driving Alertness': Contribution to Total Variance: 6·4%	
I am on the alert on a difficult road	0·81
I increase concentration on a difficult road	0·74
Slow moving vehicles are a traffic hazard	0·55
I am always ready to react to other drivers' unexpectbd manoeuvres	0·42
An accident is always possible because of other drivers' poor judgement	0·41
'Irritation when Overtaken': Contribution to Total Variance: 4·8%	
I feel bothered when overtaken at a junction	0·64
I feel angry when overtaken at a junction	0·62
I feel anxious when overtaken at a junction	0·58
'Overtaking Tension': Contribution to Total Variance: 3·5%	
I do not feel indifferent when overtaking another vehicle	0·64
I feel satisfied when overtaking another vehicle	0·62
I feel tense when overtaking another vehicle	0·46
'General Driver Stress': Contribution to Total Variance: 15·7%	
I am annoyed to drive behind slow moving vehicles	0·70
When I try but fail to overtake I am usually bothered	0·66
When I try but fail to overtake I am usually frustrated	0·66
I am usually patient during the rush hour	0·53
When irritated I drive aggressively	0·52
Annoyed when traffic lights change to red when I approach them	0·52
I do not feel indifferent when overtaking another vehicle	0·50
In general I mind being overtaken	0·49
Driving usually makes me feel aggressive	0·48
Driving usually makes me feel frustrated.	0·48
I am more tense on new than familiar roads	0·47
I lose my temper when another driver does something silly	0·46
I feel tense when overtaking another vehicle	0·43
Driving a car gives me a sense of power	0·43
I feel bothered when overtaken at a junction	0·43
I feel satisfied when overtaking another vehicle	0·40

Figure 3. Factor structure of the DBI (study 2) and items loading on each factor (Gulian, 1989).

Gulian et al. believe that driver stress is a "compound function of factors intrinsic (traffic conditions) and extrinsic (personal life) to driving" (1988). To test this idea, analyses were carried out to determine which categories of questionnaire responses could be used to predict reported driving stress levels. Variables not related to driving, such as life stresses and age, are predictive of four of the five previously identified driving factors, as well as the general driving stress factor identified in the single factor solution. Specifically, higher life stress was associated with higher driving stress, and increasing age was associated with increased dislike of driving. The relationship between life stress and driving will be further discussed in the next section of the paper.

Synodinos and Papacostas (1985) also conducted a factor analysis of driving behaviors. Their instrument is called the Behaviors in Traffic (BIT) questionnaire. It consists of 26 five-point response scales which measure time-urgent behavior in traffic situations. Factor analyses of the BIT reveal four factors that account for 43% of the variance in responses. The factors can be labelled as ursurpation of right-of-way, freeway urgency, externally-focused frustration, and destination-activity orientation.

These two factor analytic studies show that driving stress is not a singular concept. It is made up of a number of different frustrations that have in common only the fact that they all occur in the driving situation. The finding that driving stress can be predicted by non-driving variables has a further implication for our model. If individual difference variables such as age and life stress can affect driving stress levels, the experience of driving stress cannot be a direct function of the road and traffic environment. Rather, for these type of mediators to operate, driving stress must be a function of the environment _plus_ the individual. This connection occurs at the level of perception and interpretation, and a model of driving stress should concentrate on this interface. Transactional stress models, with their emphases on individual perception and cognitive appraisal, focus specifically on these processes and thus may be the best models for explaining driving stress. Two researchers, Gstalter and Helander, have proposed models of the driving situation (but not of driving stress specifically) that incorporate elements of transactional models.

Gstalter (1985) has proposed a theoretical approach to the driving situation that takes the form of a continuous loop: the objective traffic situation is perceived by the individual on the background of his or her personal experiences. The individual then compares this perceived situation with his or her perceptions of the coping possibilities. This comparison results in a subjective level of confidence in one's ability to control the situation. This leads to decisions between possible actions, and the action itself leads to a change in the objective situation, thus closing the loop. Gstalter further speculates that the cognitive-emotional parts of the comparison process will decrease in importance as the actions associated with the driving task become more practiced and essentially automatic.

Helander (1975) has also proposed a model of the driving system that emphasizes the interactions between the driver, the vehicle, and the environment. According to this model (Figure 4, below), the properties of the environment are embodied in the concept called environmental complexity. This includes the static environmental features, such as the road surface and surroundings, and dynamic environmental features, such as one's own car and the other traffic on the roadway. The driver perceives this environmental complexity, not objectively, but through processes that are influenced by one's personal attitudes, motivation, and knowledge.

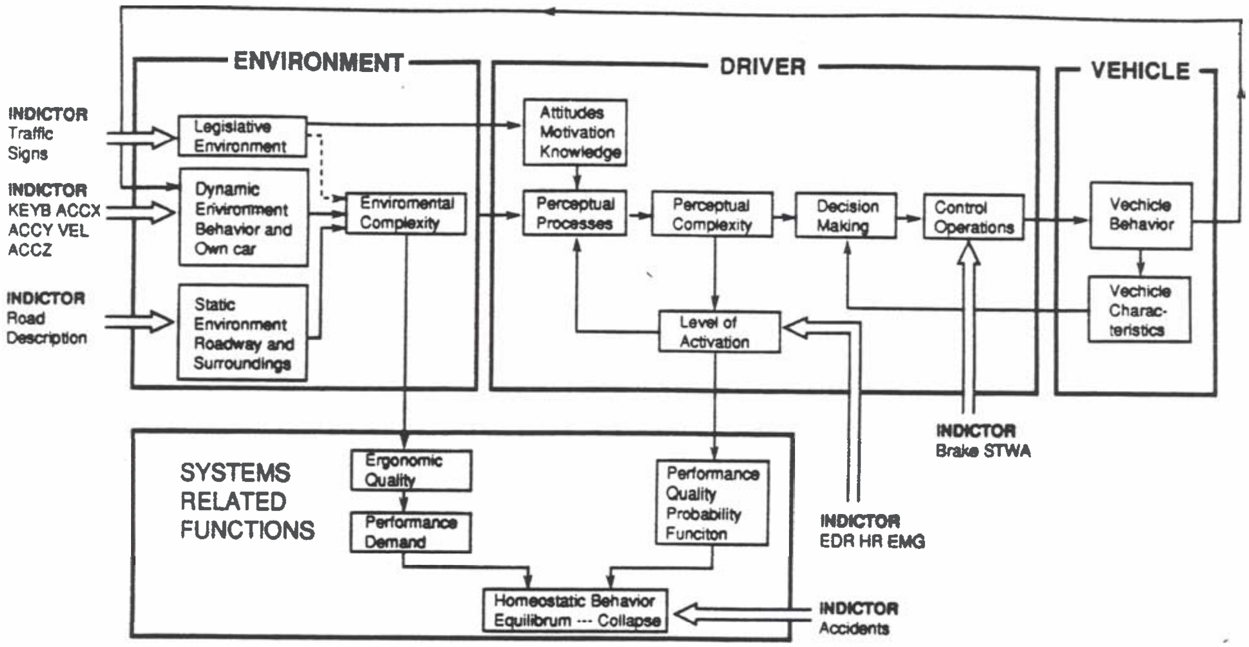

Figure 4. A model of driver, vehicle, and road system interactions in the driving situation (Helander, 1975).

Perceptual complexity, the driver's interpretation of environmental complexity, describes the total influence of the environment on the driver. The level of perceptual complexity determines the activation level of the driver. Activation level can be measured through physiological correlates such as heart rate and galvanic skin response. Activation level, in turn, affects performance in terms of vehicle control operations, which affect the external environmental situation.

Neither of these two models directly deals with the idea of driving stress, but it is apparent at what point such a concept would enter each scheme. In Gstalter's model, the perceived situation is compared with perceived coping possibilities to arrive at a subjective confidence level. If the perceived situational demand exceeded coping abilities at this comparison point, stress would result. In Helander's model, perceptions of environmental complexity influence the driver's activation level. A high activation level is a necessary prerequisite for the experience of stress.

It is at this point, then, that the concept would enter into the model.

We can combine features of these two models to create a useful model of driving stress. From Gstalter we can borrow the cognitive appraisal process in which the perceived driving situation is compared to perceived coping abilities. From Helander we can borrow an emphasis on the interaction between the driver and the road system and on the influence of non-driving variables such as attitudes and motivation on the perception of the environment.

This driving stress model is shown in Figure 5 below. The level of

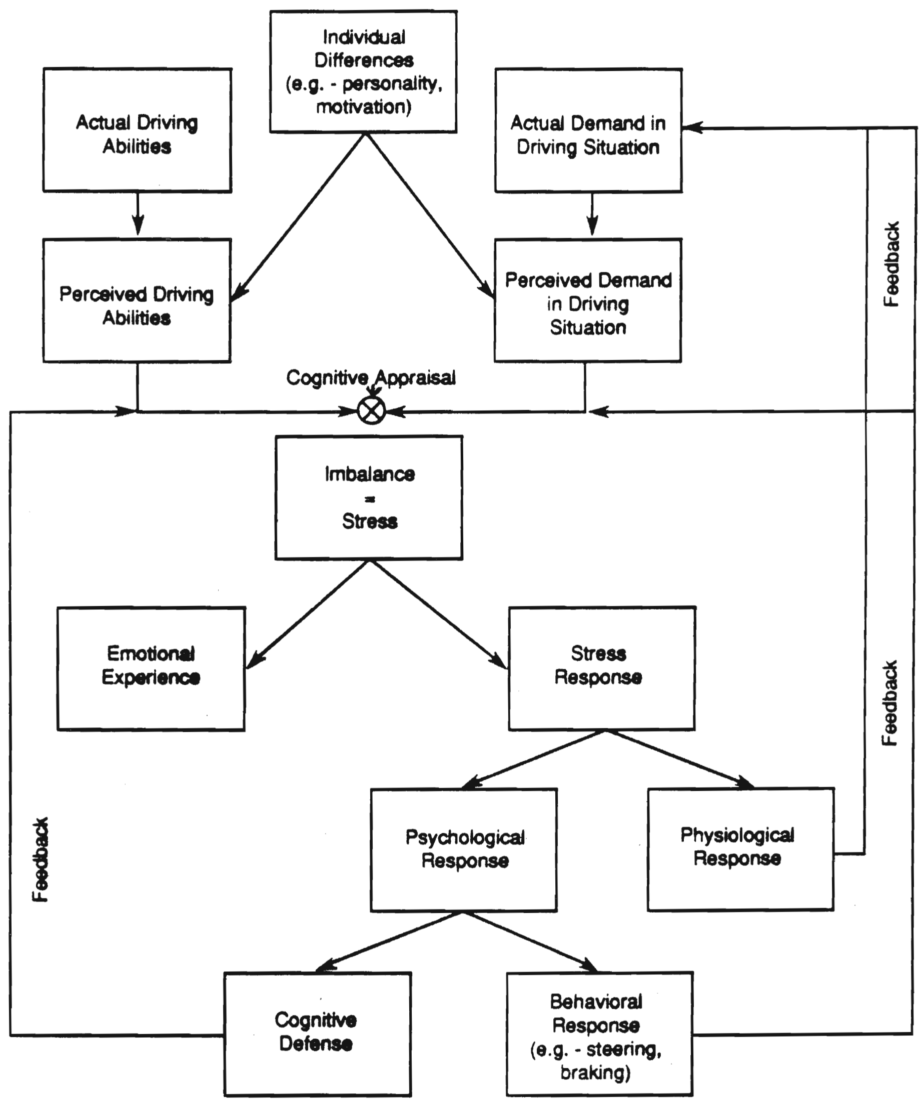

Figure 5. A transactional model of driving stress.

demand in the perceived driving situation, which is a function of the actual situation and of other non-driving variables, is compared with the level of perceived coping abilities, which is a function of actual abilities and other individual difference variables. If coping abilities are judged to be inadequate to deal with the immediate situation, stress results. This involves both a subjective emotional response and specific psychological and physiological changes. Active attempts to cope with the stressors in a driving situation are primarily behavioral (steering, increasing or decreasing speed, etc.). However, it is possible that cognitive strategies might also be used in some driving situations (e.g., when other road users will not allow the driver to change lanes). These coping responses change the situation, which is then reappraised. If the overall situation is still stressful, the cycle continues.

The immediate psychological and physiological effects of driving stress, however, are only part of its total effect. Continued exposure to driving stresses also has a cumulative effect on the individual. Since this model shows how driving stress is produced, rather than enumerating all of its possible consequences, these long-term effects are not specifically indicated. However, driving stress may produce long-term changes in the health and subjective well being of the driver. These effects are not limited to the driving process, but may affect other aspects of the individual's life, such as work productivity and residential satisfaction.

Stressful Life Events and Driving

It has been previously mentioned that life event stress is associated with high levels of driving stress (Gulian et al., 1989). Life event stresses have been the subject of many studies, most of which have been concerned with the connection between life changes and illness. It has been suggested (Selzer and Vinokur, 1975) that the influence that these stressors have on the individual might include changes in mental functions that directly influence behavior. Specifically, life event stress might affect mental functioning in such a way that driving behavior changes and the likelihood of accidents increases. An accident clearly represents a situation in which situational demands exceeded coping abilities, and thus accidents may be viewed as extreme examples from the range of driving stress situations. If Selzer and Vinokur are correct, life event stress may reduce an individual's behavioral coping ability or alter the cognitive appraisal process in such a way that driving stress is increased, resulting, in the most extreme situations, in increased accident rates.

Experimental evidence supports this line of thought only indirectly. Rather than evaluating the coping abilities and mental processing skills of individuals with different levels of life stress, studies have typically been limited to comparing the life stress levels of individuals who have had an accident with those who have not had an accident. For example, Brown and Bohnert (1968) report that 80% of their sample of 25 drivers who were involved in fatal accidents had been under serious stress prior to the accident, while only 18% of a matched sample of 25 drivers who had not been in an accident reported being under such stress.

Selzer (Selzer, Rogers, and Kern, 1968; Selzer, 1969; Brenner and Selzer, 1969) has conducted a similar study. He compared 96 drivers who had been at fault in fatal accidents with a matched control group who had not been in an accident. Fifty-two percent of the fatal accident group had experienced recent social stress while only 18% of the controls reported similar events. The types of stresses reported included serious and disturbing conflicts with significant others, the death or serious illness of a loved one, vocational difficulties, and financial problems. Interpretation of this result is complicated by the fact that the fatal accident group also exhibited a higher rate of psychopathology, including alcoholism, paranoia, depression, and suicidal thoughts, than the control group. If the alcoholics in the fatality group are excluded from the analysis, rates of psychopathology do not differ between the two groups, but those drivers in the fatality group still reported significantly more life stresses than the controls (42% vs. 18%).

A slightly different sort of investigation was conducted by McMurray (1970). Accident and violation rates of individuals involved in divorce proceedings were compared to average population levels. Subjects were grouped into four categories (male plaintiff, female plaintiff, male defendant, and female defendant) for analysis. During the seven year period covered by the driving record, the accident rates for those people involved in divorce proceedings were from 43 to 82% higher than the average rates. Violation rates were 78% to 195% higher. Similar results were found for the one year period associated with filing the divorce petition (from six months before to six months after the filing of the document). For all four of the groups studied, the period of greatest accident and violation activity was the first three months after filing the divorce petition (see Figure 6, below). The types of violations for which the

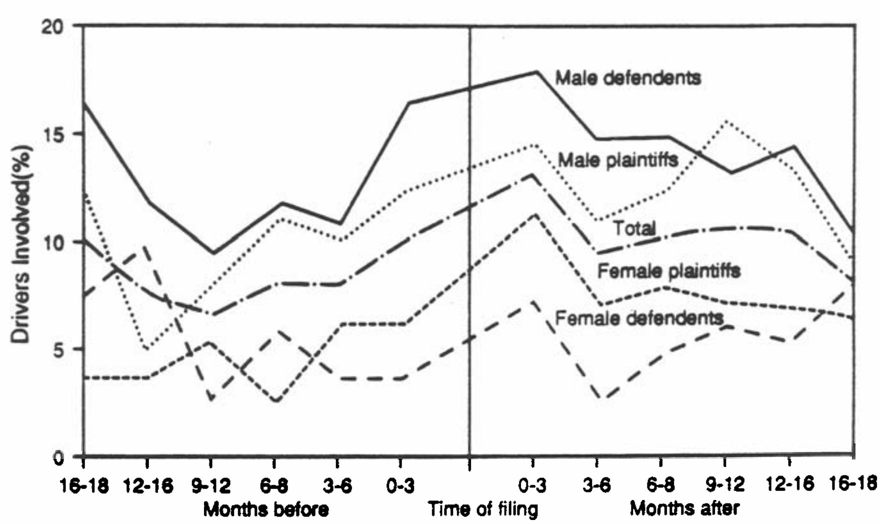

Figure 6. Percentage of drivers involved in accidents and violations before and after filing for divorce (McMurray, 1970).

divorce group were cited differed from the average types of violations in the population. Fewer serious violations (those requiring mandatory license suspensions) were found in the divorce group, but minor violations involving speeding, failure to yield, and failure to stop occurred more frequently in the divorce group than in the population at large.

These studies do suggest that driving stress, as evidenced by accident and violation rates, is greater in individuals who have experienced recent significant life stresses than in those who have not. One group of drivers in which this relationship may prove to be particularly strong is the elderly driving population.

DRIVING STRESS AND THE ELDERLY

The driving population of the United States is aging. In 1988, only 11.3% of the population was over 65 years of age. This group is expected to increase to 16.9% by the year 2000, and by 2030, over 20% of the population will be over 65 (U.S. DOC., 1981, 1984). Figure 7, below, shows these changes graphically. The number of licensed drivers within the

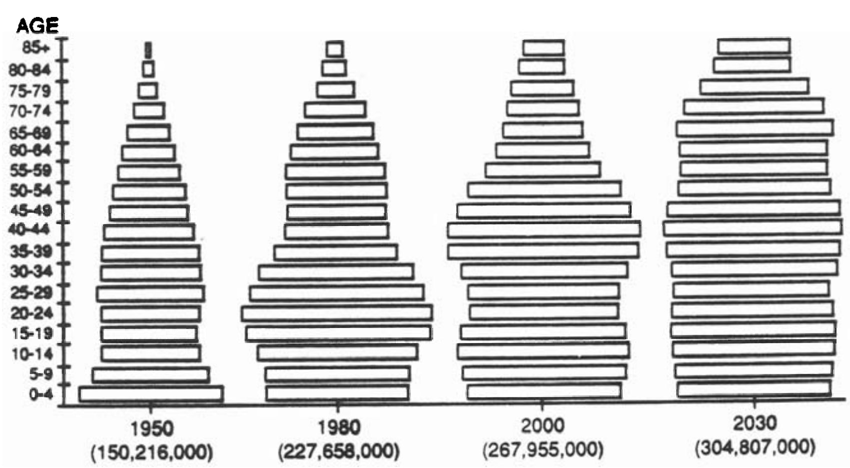

Figure 7. Age distribution of the U.S. population, 1950-2030 (Transportation Research Board, 1988).

elderly group is also increasing. Elderly drivers will make up a larger percentage of the driving population, and, therefore, the problems that elderly drivers may have with stress in the driving situation are particularly important.

It is a fairly well established fact that elderly drivers are involved in a disproportionately large number of traffic accidents. In particular, elderly drivers tend to be involved in miltivehicle accidents to a greater extent than other drivers (McKelvey and Stamatiadis, 1989). Given that an elderly person is involved in an accident, there is an 83.1% chance that it is a multi-vehicle accident. The corresponding figure for the total driving population is 75.4%. Crashes involving older people are most likely to occur on non-Interstate arterial roads (62%) in urban areas (81%) (Overend, 1986).

McKelvey and Stamatiadis (1989) consider accident data in terms of a relative accident involvement ratio. The proportion of vehicle-miles travelled for each age group is compared to the proportion of accidents for that age group. If the ratio is greater than 1.0, the group is considered overinvolved in accidents for their exposure level. The ratio of percentage of accidents to percentage of vehicle-miles of travel is 1.09 for older drivers, 2.22 for younger drivers, and 0.72 for middle-aged drivers.

Another metric for comparing relative accident involvement for various age groups involves a comparison between the percentage of accidents in which the driver is at fault and the percentage of accidents in which the driver is an innocent victim. This measure shows that drivers between 60 and 69 years of age have a relative accident exposure ratio of 1.01. Those 70 to 74 have a ratio of 1.32, and those over 75 have a ratio of 1.89. For comparison, the ratios for drivers under 25 and from 25-59 are 1.20 and 0.86 respectively.

The absolute number of driver fatalities decreases with age (Figure 8)

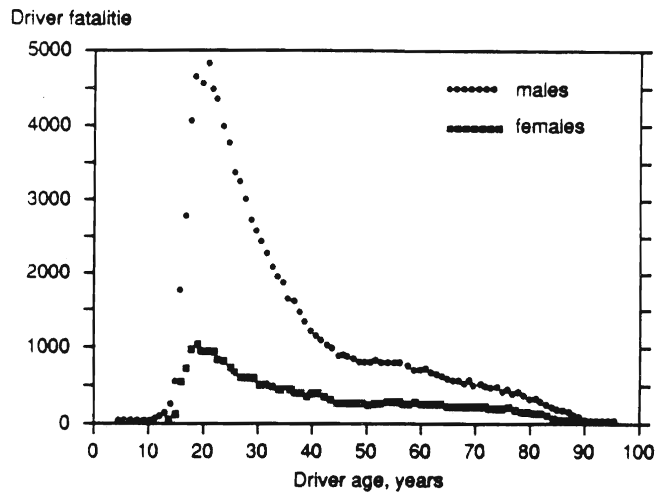

Figure 8. Number of driver fatalities, 1981-1985 (Evans, 1988).

but the number of driver fatalities per million population increases significantly for males, and slightly for females, after age 70 (Figure 9) (Evans, 1988).

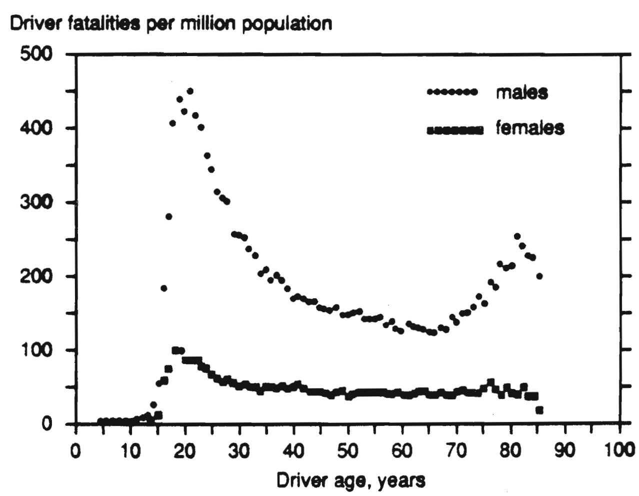

Figure 9. Driver fatalities per million population, 1981-1985 (Evans, 1988).

The number of driver fatalities per million licensed drivers evidences a similar increasing trend (Figure 10),

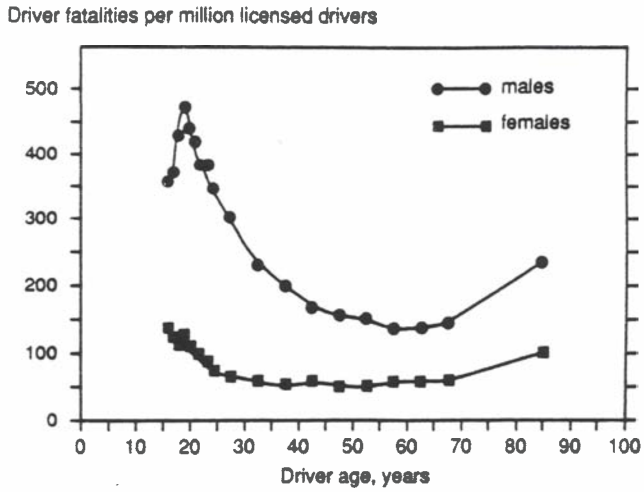

Figure 10. Driver fatalities per million million licensed drivers, 1983 (Evans, 1988).

as does the number of driver fatalities per unit distance of travel (Figure 11).

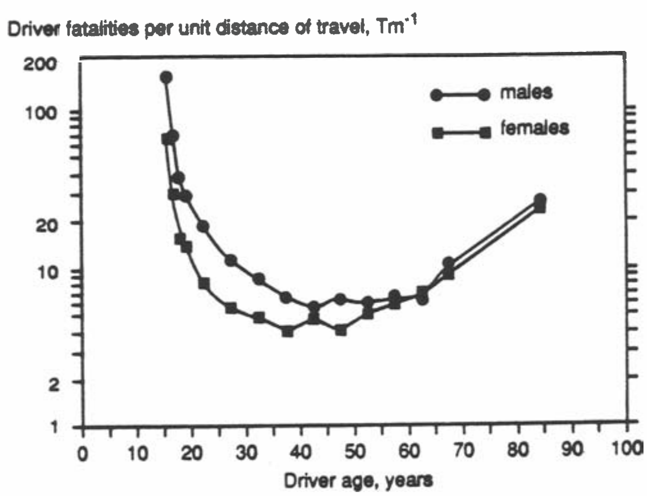

Figure 11. Driver fatalities per terameter (1 Tm = 621 million miles) of travel, 1983 (Evans, 1988).

Evans suggests that the increases in driver fatalities may, in fact, be due to the fact that a crash of given serverity is more likely to prove fatal to an elderly driver than to a younger driver. It is possible to compute "equal severity ranges," and the number of involvements in crashes in the severity range necessary to kill an 80 year old male shows no upward trend after age 70 (Figure 12).

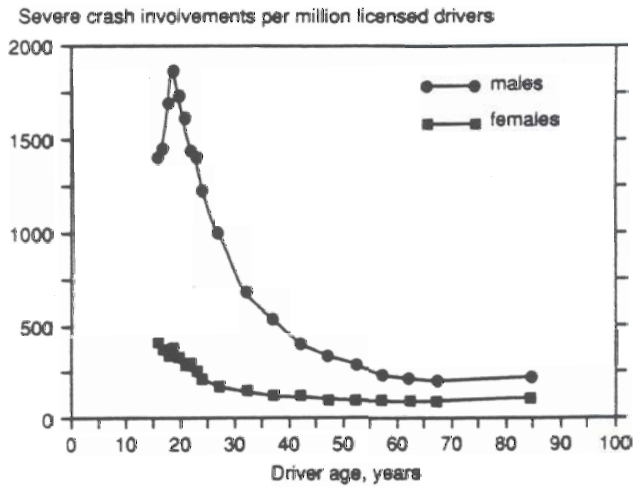

Figure 12. Estimated driver involvements in crashes of sufficient severity to kill 80-year-old male drivers per million licensed drivers (Evans, 1988).

In terms of involvements per unit distance, the upward trend is still evident, but it is smaller than that found in the non-adjusted data (Figure 13).

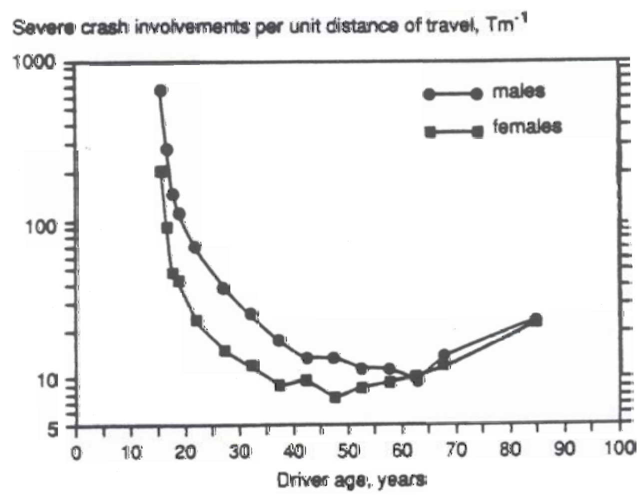

Figure 13. Estimated driver involvements in crashes of sufficient severity to kill 80-year-old male drivers per terameter (1 Tm = 621 million miles) of travel (Evans, 1988).

It should be noted that in no case did the accident involvement of elderly persons exceed that of very young drivers. In all cases when the risk at age 65 exceed that at age 40, the increased risk is primarily bourne by the driver.

Selzer and Vinokur (1975) suggest that life event stress can account for the high accident rates of elderly drivers. Old age may be accompanied by a great many different life stresses, including retirement, a drop in income level, alienation or isolation from children, illnesses and injuries, and the deaths of friends and relatives. Experiencing such stresses may place a great demand on the individual's mental coping resources, leading to a decline in performance on driving, and perhaps many other, tasks.

Research has shown that the life events included in most standardized measures are, in fact, experienced less frequently by older people than by younger and middle-aged adults. However, these age groups also differ in the type of events experienced. Though older adults report fewer life events, they also report greater unhappiness and more intrusion on their lives as a result of those events (Chirboga and Dean, 1978).

There is another reason to expect that elderly drivers may be especially susceptable to driver stress. The interactionist model suggests that stress occurs when perceived demands exceed perceived capabilities. The fact that some actual abilities decline with age leads one to expect that the amount of stress induced by a given situation may be greater for an elderly driver than for a younger driver. Deteriorating vision, in particular, may make the driving task more difficult for the older driver. Both static and dynamic visual acuity decline with age, making the discrimination of detail of both stable and moving objects more difficult. Older persons also tend to experience a narrowing of their visual field and often develop greater sensitivity to glare. Cognitive changes that accompany aging, including changes in attentiveness, estimation skills, and speed of information processing, may further complicate the driving process. These deficiencies create problems for elderly drivers in situations that force the aged driver to keep pace with traffic, requiring the quick and efficient processing of a great amount of (primarily visual) information (for example, at complex intersections) (Planek, 1971).

In fact, many older individuals are aware of their deficits in these areas, and they may often try to compensate for such difficulties. Forty percent of people 55 and over report difficulty seeing at night. Thirty-two percent report difficulties in merging and exiting in high speed traffic, and 27% report difficulty in reading traffic signs (Transportation Research Board, Special Report 218). Elderly individuals recognize that they have problems in a number of driving areas, including turning at intersections and driving under adverse conditions (Cooper, 1990). To cope with these difficulties, elderly individuals may decide not to drive at night, or in rain or snow. They may scale back the number of trips that they take, or decide to drive only within a certain well-known area. However, this type of coping behavior is not always effective, in part because some the specific situations in which elderly drivers do, in fact, perform inadequately are not recognized by the elderly individuals as problem areas. Elderly individuals are more likely to admit to relatively minor problems (such as disobeying traffic control devices) rather than to much more common violations such as failure to yield.

Finally, there is one more reason to suspect that older drivers may be particularly prone to driving stress. Elderly people may have more pronounced stress reactions, in terms of cardiovascular output and other physiological responses, than younger individuals (Chebotarev and Korushko, 1987). These researchers suggest that "a considerable decrease in adaptive capacities [may be] observed with aging."

PHYSIOLOGICAL MEASUREMENT OF DRIVING STRESS

The immediate effects of driving stress that have received the most attention from researchers are physiological changes. Physiological responses to stress involve two types of reactions: specific and non-specific. Specific physiological reactions occur only because of the unique nature of the stressor. Non-specific physiological reactions occur in response to most, if not all, stressors. Reactions to temperature extremes illustrate this distinction: intense heat produces profuse sweating while cold produces shivering, but reactions to both temperature extremes involve increased adrenocorticoid activity. In this case, shivering and sweating are specific effects that are elicited only by certain kinds of stimuli. Increased adrenocorticoid activity is a non-specific effect that occurs in response to a very wide range of stressors. Specific effects may, on occasion, modify the non-specific effects.

Since the physiological response pattern that characterizes driving stress is not particularly well documented, we should most appropriately concentrate on investigating the non-specific stress response associated with this activity. The essential factor in any stress response is sympathetic nervous system (SNS) activation. The SNS is one of the two branches of the autonomic nervous system. The sympathetic branch is primarily responsible for preparing the body for "fight or flight" when confronted with a dangerous situation. The SNS innervates most major organs. Sympathetic activity generally involves increasing cardiovascular output and decreasing digestive function. Under stressful conditions, the sympathetic system is responsible for increasing heart rate, dialating the bronchi in the lungs, and interrupting digestion. The opposing branch of the autonomic nervous system, the parasympathetic system (PNS) innervates most of the same organs, but has an opposite effect on their functioning.

The PNS slows heart rate, constricts the bronchi, and promotes digestion. Thus the level of functioning for many organs depends on the level of activation of both the sympathetic and parasympathetic systems.

Some physiological reactions, however, are entirely controlled by the SNS. These singularly controlled reactions include sweating, the secretion of hormones from the adrenal glands, constriction of the blood vessels, and piloerection ("goose bumps"). These reactions are the exclusive province of the SNS. The parasympathetic system plays no part in controlling these physiological functions.

Physiological reactions to stressors are also produced by a somewhat more circuitous route than direct SNS activation. It was mentioned above that the SNS innervates the adrenal glands. These glands lie at the superior poles of the kidneys. The adrenals consist of two effectively independent parts, the medulla and the outer cortex. The splanchnic nerve of the SNS controls the release of catecholamines (adrenalin and nonadrenaline) from the chromaffin cells of the adrenal medulla. Adrenalin increases heart rate and cardiovascular output and increases the rate and depth of respiration. Adrenalin also mobilizes glucose as a source of energy. Noradrenaline is also associated with increases in respiration rate, and this catecholamine is involved in blood pressure control through changes in peripheral resistance.

The adrenal cortex secretes three types of steroid hormones, including the glucocorticoids cortisol and corticosterone. These hormones also have catabolic (preparation for fight or flight) effects on the body. The release of these hormones is governed by the level of adrenocorticotropic hormone (ACTH) in the blood. ACTH is secreted by the anterior lobe of the pituitary gland, and its release depends, in turn, on the release of corticotropin-releasing factor (CRF) from the hypothalamus. There are, then, several simultaneously operating systems that affect physiological reactions to stress, which may produce complimentary or contradictory effects on various bodily organs.

Experimental studies of the physiological indexes of stress typically involve the measurement of only a few variables. These include a number of cardiovascular variables (heart rate, electrocardiograph patterns, heart rate variability, and blood pressure), galvanic skin response, and levels of catecholamines and corticosteroids.

Many of these indexes are electrophysiological measures. The fundamental principle involved in such measurements is that a difference exists in the concentration of charged ions in cells and in the surrounding fluid. The cells are, therefore, polarized. When a nerve cell operates, it depolarizes as ions flow across the cell membrane. This change of electrical potential can be measured if a group of cells are all working synchronously. These differences can be detected by electrodes on the surface of the skin, where they are amplified and recorded. The placement of the electrodes determines which set of potentials is recorded. The electrocardiogram, which measures the changes in electrical potential of the heart muscle is the most common example of this sort of measuring device.

The potential differences in a beating heart have a characteristic waveform that corresponds to the systematic polarization and depolarization of different areas. This waveform, when recorded with a carefully specified standard electrode placement, is depicted in Figure 14.
The maxima and minima of the waveform are labelled in a standard fashion. Typical findings in stress-related studies show changes in the size of the T wave or in the S-T segment under stressful conditions.

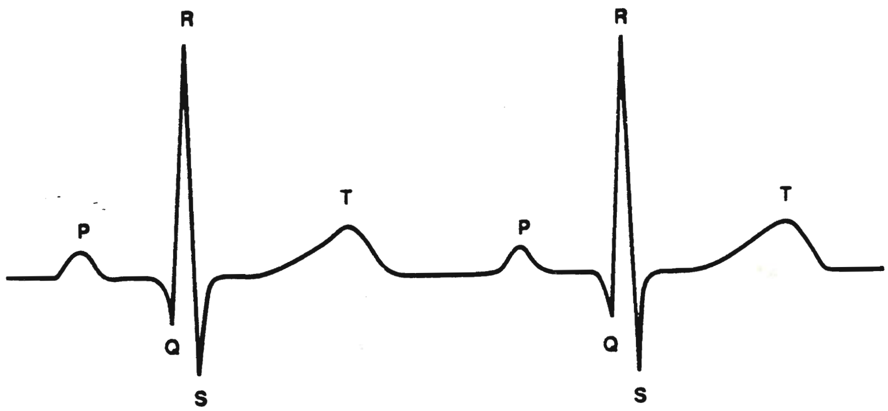

Figure 14. The ECG waveform (adapted from Robertson, 1988).

The ECG may also be used to determine heart rate. Heart rate is defined as the frequency at which the heart beats, and it is typically expressed in beats per minute. One way to determine heart rate is to count the number of waveforms present on the ECG tracing for a given time period. A more sensitive measure of heart rate is the instantaneous heart rate, which is the reciprocal of the interbeat interval, which is the time elapsed between successive identical points of the ECG.

Heart rate variability refers to how evenly and steadily the heart beats. This measure is typically expressed in terms of the standard deviation of instantaneous heart rate over some specified period of time. Other measures of HRV involve the calculation of coefficients that take the effect of heart rate on heart rate variability into account. A third way of measuring HRV involves spectral analysis. Any periodic waveform may be analyzed to determine the frequency and amplitude of its sinusoidal components. In applying spectral analysis to HRV, a series of beats is considered as a single waveform, and the variability in heart rate is detectable as a very low frequency component.

Blood pressure is the amount of pressure exerted upon the inner surface of blood vessels, expressed in millimeters of mercury (mmHg). Diastolic pressure is the amount of pressure on the vessel wall when the heart contracts, and systolic blood pressure is the amount of pressure on the vessel wall while the heart muscle is relaxed. Measurements of blood pressure can be made externally, using a sphygmomanometer, or, more accurately, using a catheter placed inside a blood vessel. Blood pressure typically rises in stressful situations.

Another physiological measure that is frequently employed in studies of stress responses is galvanic skin response (GSR). This measure is also known as skin conductance response (SCR) and electrodermal response (EDR). Typically, a pair of electrodes is used to measure the level of electrical resistance of the skin. Conductance is the reciprocal of resistance. A drop in resistance (increase in conductance) occurs in response to stressful stimuli. Several different measures of GSR can be used, including basal levels of skin conductance, relative increases in response to specific stimuli, and measures of relative increases averaged over some unit of time.

Levels of catecholamines and corticosteroids can also be used as indicators of stress. Catecholamines may be measured by analyzing blood plasma, but analyses of adrenalin and noradrenaline levels in urine are more common. Corticosteroid levels are determined by measuring the urinary levels of certain substances which result from the breakdown of these compounds.

PHYSIOLOGICAL CHANGES ASSOCIATED WITH DRIVING

The next section of text is essentially a catalog of a large number of studies that have examined physiological variables in the driving situation. If driving is, in fact, an environmental stressor, driving tasks should be accompanied by a certain set of general physiological responses very similar to those evoked by other stressful stimuli. The physiological changes that we would expect to find in a driving situation include cardiovascular changes (heart rate increases, blood pressure increases, changes in heart rate variability and in electrocardiographic patterns), changes in GSR level and frequency of response, and changes in the blood plasma and urinary levels of certain chemical substances (most notably catecholamines, such as adrenalin and noradrenaline, but also corticosteroids).

It should be emphasized, however, that the physiological changes that occur when driving may be due to a number of different factors. For example, McDonald (1984) lists three possible interpretations of the heart rate changes that typically accompany driving: physical, attentional, and emotional. Driving does require some physical effort, both in maintaining posture and in control movements such as steering and braking, and physical effort is known to affect many physiological indexes in the same way that stress does. Driving also requires increased attention, which is known to be accompanied by heightened physiological arousal. The emotional stress of driving is not easily separable from either of these two factors, and it could be argued that the attentional and emotional explanations should not be disentangled from each other, particularly when discussing anxiety generating high traffic situations. It is not clear whether high task demand causes anxiety, or if the attentional mechanism and the emotional mechanism are both activated simultaneously and independently by the same features of the environment.

For the sake of clarity, the studies are grouped together according to the type of comparisons made (e.g., driving vs. non-driving, well illuminated vs. poorly illuminated conditions) and, in areas that have generated a large number of investigations, by the type of physiological index employed in the study.

Driving/Non-Driving Comparisons

A number of different studies have compared the levels of various physiological indexes under driving and non-driving conditions. Usually, a measurement of a physiological variable is made while the subject is resting, and then this baseline level is compared to the level of the variable during or just after the driving task. Any difference between the two is considered to be caused by the driving.

Heart Rate. Heart rate is typically higher while driving than while resting. For example, Wyss (1970) found that the average heart rate of 84 subjects increased from a resting level of 71 +/- 8 bpm (beats per minute) to 90 +/- 11 bpm while subjects drove their own cars over a number of different routes. Taggart, Gibbons, and Somerville (1969) found that 91% of normal subjects exhibited a heart rate increase while driving their own cars in heavy traffic in the vicinity of Picadilly Circus and Trafalgar Square in London, an area with which all subjects were familiar. When 24 subjects with coronary heart disease (CHD) drove the same route under similar conditions, 21 showed heart rate increases over the resting level. The highest reported heart rate for the normal group was 155 bpm; the highest reported heart rate for the CHD group was 180 bpm.

Taggart, Gibbons, and Somerville also studied race car drivers during competition. This sort of situation may exaggerate the kind of stresses present in more typical everyday driving tasks, thus making the specific physiological changes involved easier to identify and examine. During the 15 minute period before the start of the race, all 10 of the drivers showed heart rates of 150-180 bpm. By the start of the race, heart rates had climbed to even higher levels (180-210 bpm) and were maintained at these extremely high levels throughout the 20 minute event.

Bellet, Roman, Kostis, and Slater (1969) studied 65 normal subjects and 66 subjects with CHD. A variable increase in heart rate while driving was found in both groups. A 2 1/2 hour drive caused a significant heart rate increase in some, but not all, of the subjects. The highest recorded heart rate level was 145 bpm among the normal subjects, 155 bpm among the CHD subjects.

A Japanese study found that heart rate increased above resting levels in four subjects during a 29.3 km drive along a common road in Tokyo (Ohkubo, 1976). An experiment using police drivers as subjects reported a brief initial rise in heart rate at the beginning of a 30 mile drive (Hunt, Dix, and May, 1968).

There seems to be fairly broad agreement that driving increases heart rate in normal individuals and in those with heart disease. Robertson (1988) cites a number of additional studies that further support this position. Dupis (1965) found that heart rate was 15-27 bpm higher than resting levels during the first 10-20 minutes of a drive. Hashimoto (1967) found heart rate increases (of different magnitudes) on highways, town, and mountain roads. Heart rate is also elevated while driving on a closed track (Michaut, Pottier, Roche, and Wisner, 1964). Michaut et al. reported that heart rates were, on average, 26 bpm higher than resting levels at the beginning of a three hour drive. This rate decreased to 17 bpm above resting levels as the drive progressed.

Heart Rate Variability. Measurements of heart rate variability can also be obtained from heart rate recordings. The pulse rate is not perfectly stable; differences between the length of successive interbeat intervals can be detected and studied. Wyss (1970) reported that heart rate during driving shows irregular but continuous variations from +/- 8-10% to +/- 50% of the preceding value within 6-8 to 30-50 seconds. That is, the heart rate continually changes, speeding up and slowing down constantly during the driving situation. When compared to resting levels of heart rate variability, Plant (1969) reports that the standard deviations for heart rate were considerably higher when driving than when parked.

Blood Pressure. Another cardiovascular measure that may be affected by driving is blood pressure. In general, blood pressure increases are found in subjects that experience stressful situations. However, blood pressure seems to be remarkably stable while driving. Bevan (1969) found only very small changes in blood pressure (systolic -3 mmHg, diastolic +3 mmHg) when periods of driving were compared to the five minutes immediately preceding them. Differences of this magnitude are statistically insignificant. Littler, Honour, and Sleight (1973) report similar results. Their data show that arterial blood pressure remains remarkably stable in normal subjects and hypertensive subjects throughout a journey. No differences were found between the blood pressure levels at the beginning and the end of a drive. Transient periods of raised pressure were recorded (usually related to such episodes as overtaking), but these quickly returned to baseline levels. It seems that specific driving events may lead to increases in blood pressure, but driving itself does not.

Electrocardiograph Changes. The stress of driving may also cause changes in the electrocardiograph tracings of individuals with coronary heart disease, and, under certain extreme conditions, similar changes have been detected in normal individuals.

Bellet, Roman, Kostis, and Slater (1968) tested 65 normal subjects and 66 subjects with documented coronary heart disease. The ECG tracings of the normal subjects during driving were essentially identical to the ECG tracings recorded under resting conditions. However, significant ECG changes while driving were found in 11 (16.7%) of the 66 CHD subjects. The most common change was S-T segment depression, which was found in six of the subjects. This type of change is often seen in CHD patients, and it can be the result of either physical exertion or mental stress. The driving conditions in this study were not overly difficult: subjects drove familiar cars during daylight hours in their normal manner. Since the driving task in the study was very similar to the subjects' everyday commute, these researchers concluded that this type of ECG change occurs quite frequently in CHD patients, probably on a daily basis. Hoffman (1963) reports the same sort of ischemic changes in drivers with coronary disease.

Taggart, Gibbons, and Somerville (1969) compared resting and driving ECG tracings of 32 normal subjects and 29 heart patients (most with CHD). Of the 24 subjects with CHD, S-T changes occurred in 13 (54%). These changes were gross in 6 (25%). Moreover, S-T depression and flattening of the T waves were recorded in three of the normal subjects. At a later time, the normal subject with the most striking S-T changes was injected with atropine to produce the level of tachycardia (accelerated heart rate) that she had experienced while in the driving situation. No S-T changes occurred until "a sudden severe fright was administered." This suggests that the ECG changes found when driving are due to anxiety produced by the driving situation.

The subjects in the Taggart, Gibbons, and Somerville study were required to drive in dense, fast-moving traffic in the vicinity of Trafalgar Square and Picadilly Circus in London. Their driving task was certainly more demanding than that in the Bellet, Roman, Kostis, and Slater study. It is this difference in task difficulty that probably accounts for the fact that ECG changes were found in normal subjects in only one (Taggart, Gibbons, and Somerville) of the studies. Light traffic conditions may produce ECG changes in subjects whose circulatory systems are compromised. Under heavier traffic conditions, the same sort of changes begin to occur in those with normal circulatory systems. A 1965 study conducted by Hoffman provides further evidence for this interpretation. Hoffman's study showed S-T depression and a flattening of T waves in healthy persons during city driving, typically considered a very demanding task.

Another situation that has been found to produce S-T and T wave changes in normals is long distance driving. Burns, Baker, Simonson, and Keiper (1966) recorded the ECG of four normal drivers who each drove from 200 to 2600 miles over a period of one to four days. T wave changes were seen in three of the subjects. In a later investigation (Simonson, Baker, Burns, Keiper, Schmitt, and Stackhouse, 1968), a fifth subject was added. This subject also showed a lowering of the T wave after prolonged periods of driving (300 miles). These changes were very similar to those seen in the same subject during rush hour traffic conditions.

Littler, Honour, and Sleight (1973) found no S-T or T wave changes in normal, hypertensive, or CHD patients, but they acknowledge that the particular lead system that they employed in their study may have been unable to detect such changes.

Galvanic Skin Response. Mean GSR rates during driving are 50 times as great as those obtained when subjects were resting in a quiet room (Taylor, 1964). Hines (1986) reports a study in which a biofeedback monitor was used to measure GSR. The frequency of a pulsed tone rose with increased stress. Even when the driver had had sufficient time to become accustomed to the monitor, there was a rise in tone upon starting the engine.

Catecholamine Levels. Another non-cardiac measure that can be used as an indicator of stress is the level of urinary catecholamines produced while driving. Bellet, Roman, and Kostis (1969) found that mean levels of catecholamine excretion during two hours of driving were significantly higher than those found during two hours of resting in the laboratory for both normal subjects and those with CHD. Higher levels of hydroxycorticosteroids were also found in both groups during the driving period. The approximately 80% increase in catecholamines is quite consistent with the 100% increase reported by Schmid and Meythaler (1964).

Taggart, Gibbons, and Somerville (1969) measured plasma catecholamine levels in 3 men with CHD and one normal woman immediately after a drive through city traffic and again several days later (presumably not immediately after a drive). The changes that they found were generally insignificant and inconsistent. However, similar comparisons of adrenalin and noradrenaline levels in racing drivers showed that post-race levels of noradrenaline were elevated in all 10 cases, and in some drivers the post-race level was 20 times that of the resting sample. Post-race levels of adrenalin were elevated in only one of the ten drivers.

Road Type Comparisons

Certainly not all types of driving are equivalent in producing these physiological indications of stress. We have already discussed the fact that driving in dense city traffic or for long periods of time produces ECG changes in normal subjects that do not occur under less difficult driving conditions. Different types of roads tend to produce different amounts of stress, and thus differences in heart rate, GSR, etc. should be detectable.

Heart Rate. Hoffman and Schneider (1967) have conducted a study that compares heart rate levels on various types of roads. They express their results in terms of the percentage of 600 healthy drivers that experienced a heart rate increase of a certain level (20% or 40% above resting levels) under each condition. For example, none of the drivers in their sample experienced a heart rate increase of 20% or greater during highway driving in low density traffic. During urban driving, however, 28% of 600 healthy drivers produced HR increases of 20% or more, and increases of 40% or more were found in 8%. This result is supported by Berger, Bliersbach, and Dellen (1976) who also report that increased heart rates indicate that greater stress is experienced on city roads than on highways. Hashimoto et al. (1967) found that highway driving produced a 6-9% increase in HR over resting levels. Driving on town and mountain roads produced increases of 15-18%. Probst (1976) reports that well constructed highways with low density traffic produce less cardiovascular stress than twisting roads with heavy traffic.

Wyss (1970) compared six different combinations of road types and conditions. He found that the smallest increase in HR occurred during highway driving. Town driving produced larger increases, and driving up- and down-hill produced even larger increases in HR.

Robertson (1987; 1988; Robertson and Goodwin, 1988) examined the heart rates of six subjects who drove a route which included four different types of roads: dual carriageway, major rural road, minor rural road, and urban roads. For these six subjects, minor rural roads showed the least change from resting HR levels, followed by the major rural road, and the urban road, with the dual carriageway showing the greatest increase in HR. This result, a substantial increase in heart rate for highway driving, does not agree with those reported above. An additional sample of another six subjects shows a pattern that is more consistent with previous literature. This second set of rankings, from lowest to highest heart rate, is: major rural road, dual carriageway, and minor rural and urban roads.

Blood Pressure and Electrocardiograph Changes. Other measures of cardiovascular activity have not received as much attention in regard to differences produced by different types of roads. Wyss (1970) did include blood pressure and electrocardiographic measures in his study of town, motorway, and up-and down-hill driving, but no significant differences were found.

Galvanic Skin Response. GSR has also been compared for various road types. Brown and Huffman (1972) found that mean GSR was significantly higher for business district, expressway, and residential driving than for rural highway driving. The measure of GSR that the researchers employed was a relative one. The recorder was adjusted so that a startle response produced a 2 cm deflection of the pen. The measure that was used to compare the different roadways was the average number of 1/2 cm or greater pen deflections per minute.

Michaels (1960) investigated differences in tension induced by two urban routes, a major arterial to and from downtown Washington and a roughly parallel alternate route that ran through a primarily residential area. The average magnitude of GSR was approximately the same for both routes, but 30% fewer responses per minute were generated on the alternate than on the major arterial.

A later study (Michaels, 1962) differentiated between different types of expressway design in terms of the amount of tension generated while travelling on each. The four expressway designs selected for study were (1) an interstate route designed to current interstate standards, with a design speed of 70 mph, (2) a 15 year old parkway with a design speed of 50 mph and less rigorous standards in terms of curvature and grade than are presently acceptable, (3) a 10 year old urban freeway with a design speed of 70 mph and fairly modern curvature and grade, but with substandard acceleration and deceleration lanes, and (4) an expressway with less rigorous standards of curvature and grade than are currently acceptable, only partial control of access, crossovers at the median, at-grade intersections, and access to a frontage road. The magnitude of GSR per unit time measure indicated that for each of the six subjects studied, the highway built to interstate standards generated less tension than the other three highways. When a mathematical correction accounting for volume differences was applied to the data, the lowest level of tension caused by interferences with other drivers is found on the urban freeway, followed by the interstate route, parkway, with the highest tension levels found on the freeway with only partial control of access. When tension responses generated by road design features were analyzed, tension is lowest on the urban freeway, followed by the parkway, the freeway with only partial control of access, with the interstate route generating the most tension. This sort of finding is probably due to the fact that drivers regulate their speed by monitoring traffic conditions, and when traffic interferences are reduced by highway designs that restrict access, drivers increase their speed to a point where feedback from road design features provides information about performance. Data that compare the expressway, a parallel 4 lane highway without control of access or grade separation, and an urban arterial show that the 4 lane highway produced 1.7 times tension, and the arterial produced 3.34 times as much tension as the expressway.

A third study by this researcher (Michaels, 1965) compared the Maine Turnpike, a major expressway, with US 1, a parallel non-controlled access highway. Data from nine test subjects show that US 1 generated more tension (in terms of magnitude of GSR per minute) than the turnpike for all subjects, though the average amount of tension varied considerably between subjects. The range in reduction of tension among this group was from 22-61%, with an average reduction of 46%. Figure 15 shows these tension differences for each driver.

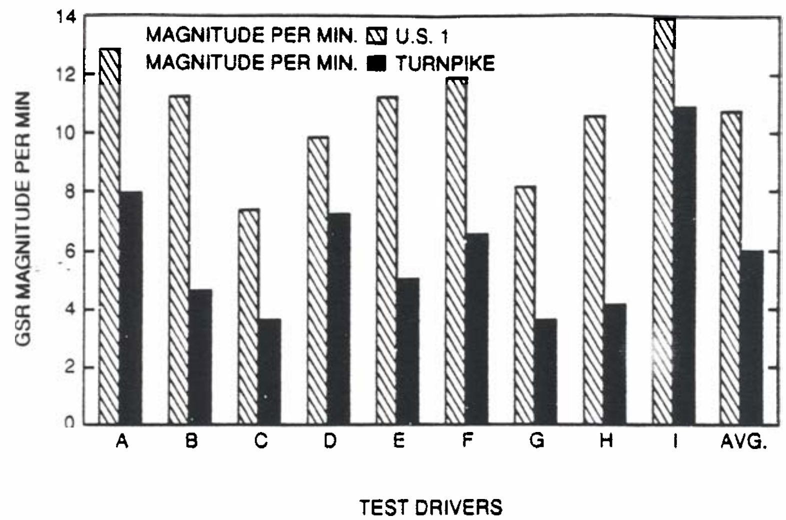

Figure 15. Mean tension generated on the Maine Turnpike and US 1 for each test triver (Michaels, 1965).

Taylor (1964) conducted a study that compared percentage change in GSR as drivers traversed a 21 mile route that contained 40 homogenous sections of different road conditions, including winding country roads, urban streets, and an expressway. The GSR rate, in nominal response units per minute, was, for the most part, quite stable across the different road sections. Some significant relationships, such as higher GSR rates for road sections containing road junctions than for immediately adjacent sections, were identified, but a constant GSR rate was maintained throughout most conditions. The researcher explains this by postulating that GSR may function as a pacing mechanism. A driver may have a certain level of tension that he or she is willing to tolerate. If road conditions impose a greater or lesser amount of tension, the driver will adjust speed accordingly.

Catecholamine Levels. Berger, Bliersbach, and Dellen (1976) report that levels of catecholamines indicate that greater stress was experienced on city roads than on highways.

Road Design Elements

Certain road elements have been shown to have a direct relationship to physiological indicators of stress. For example, Babkov (1975) reports that heart rate is higher on entering and leaving a curve than on straight sections of roadway. Also, as the radius of a curve decreases and lateral force on the car increases, GSR levels increase, as shown in Figure 16.

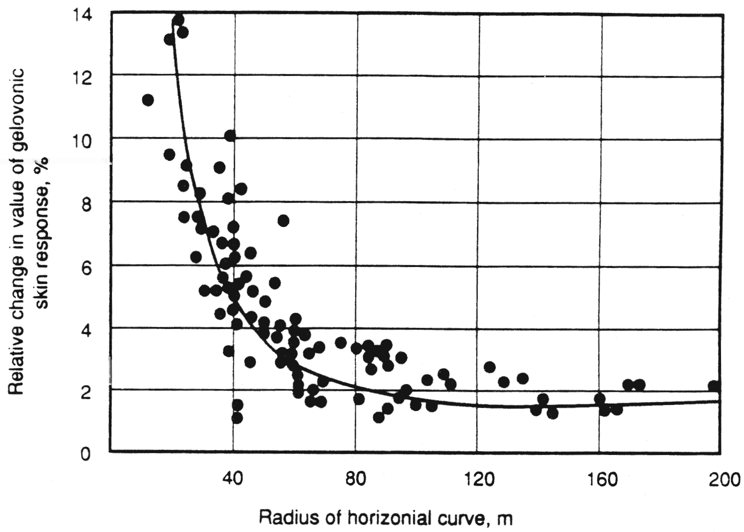

Figure 16. GSR changes associated with curves of varying radii (Babkov, 1975, reprinted in Robertson, 1988).

Engels (1978) has found that heart rate is higher on left hand bends than on other sections of roadway for those drivers who are accustomed to driving on the right.

Michaels (1962) notes that, among highway interferences, the most tension inducing are changes in pavement characteristics, followed closely by the tension induced by the negotiation of curves.

Hills also seem to be associated with increased levels of stress. Wyss (1970) found higher average heart rate levels while driving up and down hills than while driving on level town roads and expressways. Helander (1975) reports that downhill grades which require use of the brake are associated with increased levels of stress as measured by heart rate and GSR.

On-ramps also seem to be particularly stressful. Platt reports a study that showed that drivers' heart rates increase significantly during ramp entry to a freeway. Rutley and Mace (1972) investigated drivers' heart rates at different parts of road junctions. Subjects in this study drove along a motorway, exiting and reentering at each junction. Each junction consisted of five parts: pre-off-ramp, off-ramp, roundabout, on-ramp, and post-on-ramp. HR changes were expressed as percentages of a reference level which was defined as the lowest average value (bpm) obtained for that subject for any part of any junction on that run. Results show that HR rises when drivers negotiate a motorway interchange. The average percentage heart rate over the reference level for each road section can be found in Figure 17.

Part of junction.	Mean HR rise %	SD (of HR means for each subject)
Pre-off ramp	6.9	4.4
Off ramp	7.5	5.9
Roundabout	12.4	6.0
On-ramp	12.7	8.4
Post-on ramp	5.4	4.6

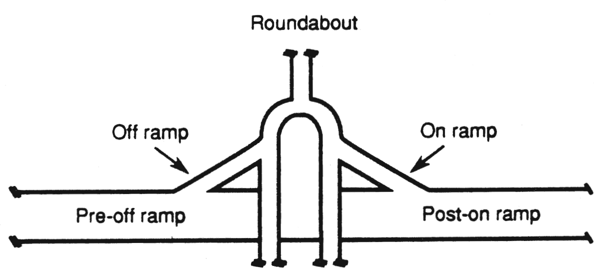

Figure 17. Mean percentage heart rate increase at different junction parts (Robertson, 1988).

The rank order of these changes is as would be expected from a subjective estimate of each segment's difficulty. The mean percentage increases for roundabouts and on-ramps are significantly greater than the values for the other junction segments. Rutley and Mace point out the fact that some of the HR increases found in this study are of the same magnitude as those evoked by simulated driving and weight lifting tasks requiring the same amount of muscular effort. Therefore, it is likely that at least part of the HR increase found at motorway junctions is due to the physical effort of performing the required turning maneuvers, but the fact that the largest HR change was found for the on-ramp, a segment requiring very little physical effort, suggests that at least some of the heart rate increases found in this study were due to mental effort or emotional factors.

Segment Difficulty Comparisons

Many studies have found that heart rate and other physiological indicators of stress tend to increase with the "difficulty" or "complexity" of the driving situation.

Heart Rate. Egelund (1983) compared heart rate and heart rate variability measures for nine drivers who traversed a 30 km route that included 19 segments representing a variety of traffic situations. The 19 road segments were placed in "complicated" or "uncomplicated" categories. The uncomplicated segments were those that placed a low demand on the driver, since they were straight roads with few and clear intersections and low traffic density. The complicated segments, however, were urban roads with multiple "incalcuable" intersections, road divisions, or highway acceleration entries, and thus placed a high demand on the driver. Segment complexity was found to be related to heart rate and a spectral analysis measure of heart rate variability. The researcher concluded that heart rate and heart rate variability both indicated aspects of mental load, heart rate in a direct, and heart rate variability in an inverse relationship. Purely arithmetic indexes of heart rate variability showed no relationship to complexity or mental load.

Dupis (1965) reports that increases in driving task difficulty related to road and traffic events such as sudden stops, acceleration, overtaking, and dangerous curves, are associated with heart rate increases of up to 45 bpm. Becker, Schwibbe, Ahlbrecht, and Steufgen (1971) found that the difficulty of a given situation was closely related to the pulse rate or its increase. Hunt, Dix, and May (1968) found that heart rate increases among highly experienced drivers were associated with particularly hazardous road segments.

Galvanic Skin Response. Cleveland (1961) found that more complex paths through an intersection generated more tension responses (GSRs) than did simpler paths through the same intersection. Helander (1975) reports that peaks in EDR activity are typically obtained at spots of increased task demand.

Accident Rates. Kaiser (1975) reports a highly significant relationship between pulse rate and accident rate on various sections of roadway. Low pulse rates were noted on road sections where the accidents were not related to driver error. Robertson (1988) also investigated the connection between accident rates and heart rates, but no significant relationship was found. However, this latter study did not separate accidents due to driver error from accidents precipitated by other causes, which may account for the inconsistency.

Taylor (1964) found that where the number of side turnings is greater, the risk of accident is greater, and the GSR experienced per mile of travel is also higher. Thus the distribution of GSR closely follows the distribution of accidents, but the causal connection in this relationship is unclear. Babkov (1975) reports an increase in GSR at accident "black spots," and suggests that the increased emotional strains of drivers at these locations were related to the high number of accidents. Helander (1975) found that the EDR of drivers who traversed a test route covaried with the rate of single car accidents that occurred in the same direction the test car was travelling.

Traffic Volume

Michaels (1962) found that the relationship between GSR and traffic volume is quite linear up to about 2400 vehicles per hour in two lanes, at which point the rise in tension appears to increase exponentially, up to a maximum tested value of 3600 vehicles per hour in two lanes. The measure of GSR used in this study was magnitude of GSR per unit time. This relationship is shown graphically in Figure 18.

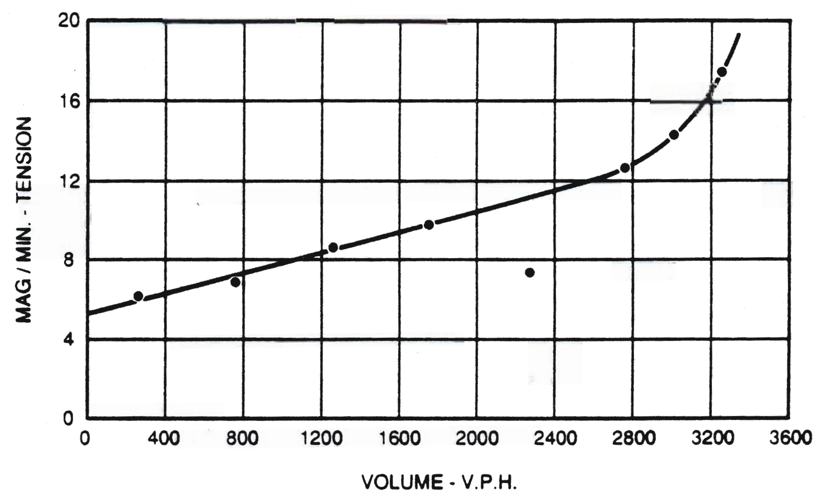

Figure 18. Effect of traffic volume on tension responses (Michaels, 1962).

Taylor (1964) reports that traffic conditions have no effect on the rate of GSR. Traffic conditions at peak and off-peak travel times produced no differences in the number of GSR responses per minute.

Traffic Events

Many experimenters have attempted to find a link between individual galvanic skin responses and specific traffic events, and most have been successful. Michaels (1960) compared traffic events on a major urban arterial and on an alternate route, as well as the tension responses generated on each route. A list of 8 traffic events was developed, and the eight kinds of interferences on this list accounted for 95% of all agents causing a change in test vehicle speed or placement. This list included parking maneuvers, marginal pedestrians, instream moving, transit loading platforms, pedestrians instream, turning vehicles, merging and crossing vehicles, and traffic signals. Approximately 15% of the traffic events observed generated no response from the driver. A traffic event was recorded once every 24.7 seconds on the arterial and once every 34.9 seconds on the alternate route. Since 85% of the traffic events generated GSRs, there was a tension inducing event once every 29.2 seconds on the arterial and once every 41.4 seconds on the alternate.

Additionally, each route was analyzed individually to determine what types of traffic events generated the greatest magnitude of GSR response. For the arterial, the highest magnitude of GSR response was generated by turning, followed by crossing and merging, traffic control devices, instream pedestrians, moving vehicles, parking, loading platforms, with marginal pedestrians generating the smallest tension responses. On the alternate route, the largest GSR was generated by crossing and merging, followed by opposing vehicles, traffic control devices, turning, moving vehicles, instream pedestrians, marginal pedestrians, with parking generating the smallest GSR. The events that generate the largest GSRs are those events in which the rate of change of location of the conflicting vehicles is at a maximum. With humans' limited accuracy in speed estimation and angular closing rate and limited time for such decisions, these situations have a high degree of unpredictability and may reasonably be the most threatening.

The later Michaels study (1962) comparing expressway designs also involved traffic events. Four traffic events, instream vehicles, merging or crossing vehicles, exiting vehicles, and pedestrians, and four design variables, gradient, curvature, pavement changes, and shoulder objects, were recorded. On expressways, two interferences, instream traffic and negotiation of curves, account for approximately 70% of all driving interferences. 90-95% of all traffic interferences are instream conflicts. On the urban freeway, over half of all interferences were caused by traffic; only about 25% of the interferences on the interstate were caused by traffic. On routes with uncontrolled access, marginal conflicts are more frequent (30% vs. 10% of traffic interferences) than on controlled access interstates.

Torres (1971) found a positive linear relationship between the number of traffic events and accumulated log conductance change in skin resistance. Surti and Gervais (1967) ranked traffic events on a freeway and a surface street in term of the magnitude of tension response and the frequency of such responses. Longitudinal friction, traffic events encountered along the direction of motion (roughly comparable to Michaels, 1962, instream conflict) accounted for the greatest percentage of the total responses for the freeway as well as the street route. The magnitude of response is thought to be an indicator of the difficulty of the driver's required decision making process. The traffic event rankings for the freeway and the surface street, in term of magnitude and frequency of response are given in Figures 19 and 20.

Freeway		Surface Street	
Rank	Event	Rank	Event
1	On-ramp merging (Event No. 3)	1	Signals and stop signs (Event No. 7)
2	Longitudinal friction (Event No. 1)	2	Longitudinal friction (Event No. 1)
3	Shoulder incidents (Event No. 5)	3	Parking (Event No. 5)
4	Off-ramp diverging (Event No. 4)	4	Pedestrians (Event No. 6)
5	Change in horizontal or vertical alignment (Event No. 2)	5	Left turn (Event No. 4)
		6	Right turn (Event No. 3)
		7	Change in horizontal or vertical alignment (Event No. 2)

Figure 19. Traffic and geometric events ranked according to degree of difficulty of driver decision process (magnitude of GSR) (Surti and Gervais, 1967).

Freeway		Surface Street	
Rank	Event	Rank	Event
1	Longitudinal friction (Event No. 1)	1	Longitudinal friction (Event No. 1)
2[a]	Change in horizontal or vertical alignment (Event No. 2)	2	Signals and stop signs (Event No. 7)
3[a]	On-ramp merging (Event No. 3)	3	Change in horizontal or vertical alignment (Event No. 2)
4	Off-ramp diverging (Event No. 4)	4	Pedestrians (Event No. 6)
5	Shoulder incidents (Event No. 5)	5	Parking (Event No. 5)
		6	Right turn (Event No. 3)
		7	Left turn (Event No. 4)

[a]Based on a magnitude distribution, Event No. 3 ranked 2 and Event No. 2 ranked 3 for the freeway; remaining events had ranks identical to frequency distribution.

Figure 20. Traffic and geometric events ranked according to frequency of tension responses (Surti and Gervais, 1967).

Hulbert (1957) developed a four category system for coding traffic events that grouped events as actual interruptions (of the ideal path of the driver), possible interruptions, actual infringements, and possible infringements. Ninety-one percent of the recorded GSRs were associated with one of these four types of traffic situations. Actual interruptions of the path accounted for most of the responses, but 23% were due to only potential interruptions, and 62% of these involved no recorded action on the part of the driver.

Helander (1975) coded 25 types of traffic events encountered by 75 subjects driving a 23.7 km stretch of rural road. Sixteen of these occurred often enough to be analyzed statistically. These traffic events were rank ordered in terms of electrodermal response and brake pressure. The most stressful events recorded in this study were (1) cyclist or pedestrian + meeting other car, (2) other car passes in front of own car, (3) multiple events, (4) own car passes other car, and (5) leading car diverges. The rank ordering of the complete list can be found in Figure 21, below.

Rank Order	EDRC Traffic Event	EDRC Traffic Event Code	EDRC Number of Events	BRAKE Traffic Event Code
1	Cyclist or pedestrian + meeting other car	23	28	23
2	Other car merges in front of own car	40	47	40
3	Multiple events	2	163	2
4	Own car passes other car	60	3 590	30
5	Leading car diverges	30	207	20
6	Own car passes other car + car-following	61	126	61
7	Cyclist or pedestrian	20	839	21
8	Other car passes own car	50	157	11
9	Meeting other car	3	1 535	3
10	Cyclist or pedestrian + car-following	21	65	1
11	Car-following	1	13 049	70
12	Car-following + meeting other car	11	353	0
13	No event	0	112 630	50
14	Parked car + car-following	71	64	71
15	Parked car	70	742	10
16	Meeting other car	10	50	60

Note: $r_s = 0.71$; $p < 0.001$.

Figure 21. Rank orders of traffic events based on magnitude of electrodermal response and brake pressure (Helander, 1975).

Heart rate responds instantly to certain traffic events that may be termed "critical situations" (Simonson et al., 1968). Increases of up to 45 bpm have been found in traffic situations requiring sudden stops, overtaking, or dangerous curves (Dupis, 1965). Hoffman and Schneider (1967) report that 42% of 600 healthy drivers produced a heart rate increase of 20% or more over resting levels during critical situations. Fourteen percent produced increases of 40% or more.

Speed and Pace Comparisons

Suenaga et al. (1965) have found that forced-pace high-speed driving causes cardiovascular changes. In their study, two cars drove from Fukuoka to Moji on the national highway. The driver of one car was allowed to select his own pace and drove according to traffic conditions. The driver of the second car was directed to drive as fast as possible, subject only to the speed limit. Subjects who drove in the normal manner showed no differences in blood pressure after the drive, and their heart rates remained stable throughout the driving period. However, the heart rates of drivers of the "runaway" car increased from the start to the end of the drive, with levels highly elevated above the normal rate. Heart rate was, on average, 15 bpm higher in the high speed, forced-pace condition than in the normal speed, self-paced condition. Post drive systolic and diastolic blood pressure were both elevated as well. Blood pressure did not return to normal levels until 45 minutes after the drive.

Zeier and Baettig (1977) have found that circulatory stress is higher at high speeds than at low speeds. Hoffman and Schneider (1967) report that heart rate is unaffected by speed when subjects drive at different speeds on a motorway. It is likely, however, that the speeds in this latter study did not significantly challenge the capacities of the subjects. Dupis (1965) reports that high-speed driving produces heart rate increases of 6-7 bpm over and above the already elevated driving levels. Robertson (1988), however, found no significant correlation between mean speed over a road section and any heart rate variable. The road sections in this experiment were of very different types, and subjects were allowed to vary their speed accordingly, so it is likely that they adjusted their velocity to maintain a steady rate of tension, and thus heart rate.

Seydal (1974) reports a negative correlation between speed and GSR. This work used different traffic environments, and one can surmise that the roads on which subjects travelled at the highest speeds were specifically designed to minimize demand on the road user (e.g., limited access highways), and those roads on which subjects travelled at lower speeds had a significantly higher frequency of tension inducing events. A similar sort of explanation is used by Taylor (1964) to explain the lack of a significant relationship between GSR and speed. He postulates that drivers pace themselves by monitoring the frequency of their GSRs, reducing speed when necessary to keep their overall tension level constant.

Driving Maneuvers

Clayton et al. (1971) report that four class 1 (expert) police drivers showed an increase in heart rate during more active patrol periods involving such actions as stopping a moving vehicle and making emergency U-turns on a highway.

Probst (1976) reports that overtaking another vehicle is stressful. Hunt, Dix, and May (1968) found that two of three inexperienced drivers showed an increase in heart rate while overtaking another car, and all showed heart rate increases while being overtaken. Littler et al. (1973) found short periods of raised arterial pressure during driving related to such episodes as overtaking.

Helander (1978) found that EDR was related to such activities as overtaking, being overtaken, and meeting pedestrians or cyclists. In general, those activities associated with the use of the brake as considered stressful, especially for inexperienced drivers. The exceptions to this general rule are passing maneuvers, which do not require brake use. Helander (1975) also reports that short sight distances are stressful.

Illumination Comparisons

Brown and Huffman (1972) report that GSR rates are lower during night driving conditions than during daylight driving conditions. However, it is unclear whether other factors, such as speed and traffic volume, also varied between the two conditions and could have possibly been responsible for the unexpected direction of this relationship.

Cleveland (1961) found than only 80% as many tension responses (GSRs) are produced under illuminated conditions when compared to the same intersection when unlighted. The magnitude of the GSRs under the lighted condition is also only about 80% of that generated under unilluminated conditions. Michaels (1960) compared the tension responses of drivers on urban streets during peak, off-peak, and night driving conditions. In some, but not all, cases, driving during peak periods produced greater magnitude of response per minute, and the data for night driving typically followed the pattern for peak period runs. Taylor (1964) reports that the presence or absence of darkness (and/or peak hour traffic) has no observable effect on mean GSR rate.

Weather Comparisons

Platt (1969) reports an investigation in which a single subject was monitored for physiological changes while driving under adverse conditions. While driving in a strong wind and with light blowing snow covering the roadway, this driver, who had a normal heart rate of 80-85 bpm, reached heart rate levels of 150 bpm (max), and the standard deviation of the heart rate (a measure of heart rate variability) was also high. These changes occurred even though speed was reduced to just 47 mph.

Neumann et al. (1978) report a study of the effects of heat and noise on physiological functioning of drivers. The "non-stress" condition in this study was defined as a temperature of 76 degrees F and a sound intensity of 55 dBA, while the "stress" condition involved a temperature of 90 degrees F and a sound intensity level (road and car noise) of 78 dBA. Subjects drove for two hours and forty-eight minutes under each of the two conditions. In the high temperature noisy condition, heart rate, GSR, and systolic and diastolic blood pressure were all higher than in the moderate temperature, moderate noise condition. Mackie and O'Hanlon (1977) conducted a similar study of heat stress. Again, significantly higher heart rate and greater heart rate variability were found in the high temperature condition.

Weir and Allen (1972) report that a lateral wind (gusting) caused an increase in heart rate from 75 to 80 bpm.

<u>Transmission Comparisons</u>

It is unclear whether driving a car with automatic transmission, which could be argued to decrease the amount of effort required of the driver by the driving task, results in lower stress levels than driving a car with manual transmission. Zeier (1979) found that the rate of adrenalin excretion, skin conductance activity, heart rate, and heart rate variability were significantly higher when driving a manual than when driving an automatic. However, Seydal (1972) reports that no differences in HR levels were found in his study comparing manual and automatic transmissions. Unfortunately, details of Seydal's investigation are unavailable, and it is not possible to resolve this contradiction without further data.

<u>Experience and Skill Comparisons</u>

Helander (1976) notes that young drivers have psychomotor capabilities that are superior to those of older adults, yet the injury rate for drivers under the age of 20 is at least twice that of 30 year olds. This appears to be an effect of experience, since increased fatality rates are obtained for the first 5 years of driving, regardless of the age at which the license is first acquired. Helander believes that GSR is a valid measure of the mental effort involved in driving.

Helander has found that the most important vehicle control variable for predicting the physiological response of inexperienced drivers were those involving longitudinal control (braking, acceleration, and velocity). For experienced drivers, however, the most important predictors were those involving lateral control of the vehicle (steering wheel angle). More frequent EDRs were recorded in experienced than in inexperienced drivers.

Stikar, Hoskovec, and Biehl (1972) have found that expected events produce different physiological responses in experienced and inexperienced drivers, but that unexpected events produce similar reactions. Unexpected skidding causes increases in HR for both experienced and inexperienced drivers, but when skidding is expected, experienced drivers show less stress.

Hoffman and Schneider (1967) report that a lower proportion of experienced than inexperienced drivers showed large HR increases in urban traffic. Ohkubo (1976) has found that the heart rate increase (over resting levels) that accompanies driving is more pronounced in unskilled than in skilled drivers.

Hunt, Dix, and May (1968) had six police drivers, three of whom were considered expert and three of whom were inexperienced, drive a 30 mile course. The mean heart rate for the experienced group (82 bpm) was lower than that of the inexperienced group (93 bpm). In situations involving "competitive conflict" between drivers, all of the less experienced drivers showed heart rate increases, while the experienced drivers did not. In response to unexpected incidents, the experienced group again showed less change. The range of interbeat intervals was used as a measure of heart rate variability, and this index showed a smaller range for experienced than for inexperienced drivers.

Brown and Huffman (1972) compared two groups of drivers: those with good driving records and those with poor driving records. The good record group was made up of 16 men who had had no accidentsor moving violations during the previous four years. The poor record group consisted of 16 men who had had two or more accidents and two or more moving violations during the same time period. The good record group had significantly lower mean rates of galvanic skin response. Drivers with poor records, then, show greater arousal. It is unclear whether this high level of physiological reactivity makes them bad drivers, or whether an inability to successfully deal with the driving situation (or perhaps some other factor) causes both the poor record and the physiological response.

Preston (1969) compared the galvanic skin responses of drivers with high and low insurance premiums on town and country roads. The high insurance group did not differ from the low insurance group in the magnitude of GSR, but the ratio of town GSR to country GSR for this group showed that the high insurance group was more reactive. It is suggested that when driving in town, most GSRs are generated by other drivers, but on country roads, such responses are generated by the driver's own behavior. Thus driving on the open road will be more affected by individual differences in the amount of risks a group of drivers takes.

Taylor (1964) found that a subject's driving experience was a consistent source of variation in GSR rate. Those drivers with less experience typically show higher GSR rates. This is shown in Figure 22.

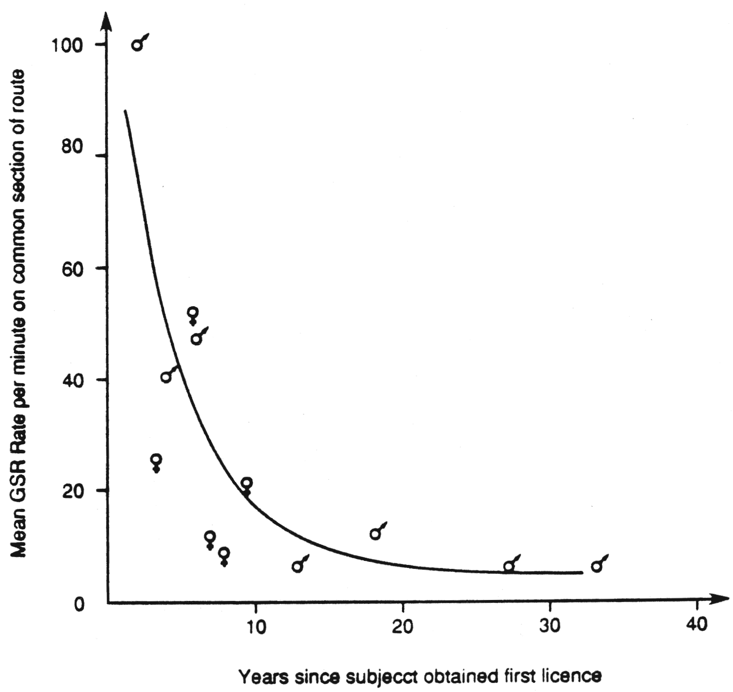

Figure 22. Subjects' mean GSR rates and amount of driving experience (Taylor, 1964).

Taylor speculates that travelling at the expected speeds on the roadway may be accompanied by a higher level of anxiety in inexperienced drivers.

Passenger Reactions

Simonson et al. (1968) report that the heart rate responses of the driver and passengers in a driving situation are nearly identical. These researchers speculate that this may be because the passenger and the driver often share the same emotional stress situation. Dupis (1965) also reports that the heart rate of passengers tends to mimic that of drivers.

Zeier (1979) found that passenger responses (heart rate, GSR, and heart rate variability) were essentially identical to driver responses in a car with automatic transmission, but passenger levels of these variables were significantly lower than driver levels in a manual. In both situations, passenger levels of muscle tension (EMG from the frontals muscle) are significantly lower than those of the driver. Torres (1971) reports that GSR is higher in drivers than in passengers.

Littler et al. (1973) found that, for the most part, arterial pressure of an individual riding in a car was similar to the pressure found when that individual was driving a car. However, in this study driving did not produce significant pressure changes, so the implication is that blood pressure also remains stable in passenger situations.

Road Markings

Babkov (1974) found that change in electrical resistance of the skin was related to road edge treatment. When edge lines were added to a section of roadway, less EDR was generated. Lower EDR was found on mountain roads with concrete edge barriers than on mountain roads without such barriers.

Interpretation of Physiological Changes

Based on evidence such as that presented above, McDonald (1984) has evaluated three possible interpretations of the physiological changes that typically accompany driving: physical, attentional, and emotional. He finds the physical explanation inadequate, based on a study by Wyss. Wyss (1971) investigated the oxygen pulse (the relationship of oxygen consumption to metabolic rate) to determine whether the heart rate increases found during driving were due to strictly physical causes. His results show that the heart rate changes produced by physical effort in the driving situation are insufficient to account for the levels of increase that are typically found. Additionally, heart rate increases have been found in situations where no control operations were necessary (Hoffman and Schneider, 1967). Wyss proposes that the causes for these heart rate increases may be primarily emotional rather than physical. This explanation is supported by researchers like Taggart et al. (1967; 1969) who have found that the cardiovascular changes that take place while driving are associated with emotional responses, such as anxiety or fear. The attentional hypothesis is also probably a valid explanation for some of the physiological changes, since task demand level (road complexity) is positively associated with physiological response level (Helander, 1976).

A number of different researchers have mentioned that physiological indicators of stress might be used by the individual as a sort of "pacing mechanism." Michaels (1962) suggests that the tension induced in driving may represent a means by which a driver may stabilize his or her system. Feedback allows the driver to determine the upper limit to his or her control of the driving situation. When traffic conditions are such that the driver is subject to considerable stress, he will slow down. When traffic is not a factor, he uses road design characteristics to obtain performance information. Helander (1976) lends support to this interpretation by pointing out that comparisons between speed limits and velocities show that the road environment, rather than the speed limit, restricts driving speed. Motorists adapt to road conditions rather than conforming to indicated speed regulations.

Gstalter (1985) similarly notes that when a situation is very demanding, drivers react with more cautious behavior, typically reducing speed. This further supports the idea of a pacing mechanism, though it is not clear whether this refers to a physiologically based pacing system, or one based on the level of information present in the immediate environment.

Taylor (1964) suggests specifically that GSR is used as a pacing mechanism while driving. Any given driver has a level of emotional tension or anxiety that he or she is willing to tolerate. If the driving situation that the driver is in generates a level of tension above this threshold, the driver will adjust his or her speed in order to bring the frequency of tension responses back down to an acceptable level. Robertson (1988) also supports a "pacing" type of explanation for the frequent failure to find a relationship between heart rate and speed. If the driver is allowed to self-select responses to the driving environment, the drivers could select an optimum speed for the conditions and would be able to maintain a constant arousal level.

CUMULATIVE EFFECTS OF DRIVING STRESS

The physiological effects of driving stress discussed in the previous section are temporary effects of the immediate environment. There is, however, another major aspect of driving stress, the cumulative effect of prolonged exposure to stressful driving situations.

Health

Perhaps one of the most important impacts of driving stress is the effect of driving on the health of the driver. Unfortunately, the effect has not been directly investigated. However, two studies, one involving the effect of commuting stress on the worker and one relating physiological stress indicators to health, can provide a basis for making predictions as to the possible impact of driving stress on health.

Taylor and Pocock (1972) have conducted a study of commuting stress and health. Their emphasis was on whether the number of absences from work was related to the length of each worker's daily commute. Employees of two large organizations were surveyed about their commutes. Each commute was described in terms of stages, parts of journeys in which neither the method of transport nor the vehicle was changed. The workers' daily commutes could include walks, rail transport, bus transport, and automobile transport. The commutes ranged from 12 minutes to 2 1/2 hours, with a median duration of one hour. The average number of stages was 2.84, with the majority having between two and four stages, with one or two by public transport. This information was then compared to the number of certified and uncertified work absences of each individual employee.

The results of this study show that the number of stages in a journey was an important factor in sickness absence. Those employees with one or two stages in their daily commute had fewer absences than those with more. The duration of the journey was important only for those individuals whose commutes were over an hour and a half long. The use of a car as the primary means of transportation was also associated with higher rates of absence.

Mulders et al. (1982; 1988) have investigated the link between driving and health in a population of professional bus drivers. The average rate of absenteeism for bus drivers in The Netherlands is twice the Dutch industrial mean. Six out of ten drivers retire early for reasons of medical disability.

Twelve subjects were selected from the population of bus drivers. Six of these were chosen for their high rates of illness absences, and six were chosen for their low rates of absence over the previous year. The high sickness group had each had five or more short absences within a years time, and the low sickness group had had two or fewer absences over the same period. Urine samples were collected from these six subjects for catecholamine analysis.

Both groups showed higher catecholamine levels after a period of work than after a rest period. The high and low sickness groups did not show differences in catecholamine levels on a day off. However, the high sickness group showed significantly higher elevations of adrenalin and noradrenaline (from resting baseline levels) than the low sickness group after a day at work. This suggests that differential physiological reactivity is associated with differential illness rates.

A later study of the same population used a similar method but incorporated a medium sickness group. As expected, the physiological reactivity (catecholamine levels) of this group fell in between that of the low sickness and high sickness groups after a day at work. No differences between the groups were found on a day off. A third study has replicated this finding. The researchers conclude that a strong link exists between increased neuro-endocrine reactivity and the early stage of progressive health impairment. Because of the design of the study, no stronger (causal) inferences could be made.

Well Being

Stokols, Novaco, Stokols, and Campbell have conducted a series of studies that explore the effects of routine exposure to traffic congestion on mood, physiology, and task performance of automobile commuters (1978; Novaco, Stokols, Campbell, and Stokols, 1979; Stokols and Novaco, 1981; Novaco, Stokols, and Milanesi, 1990). The central concept in their work is impedance. They define this term as "any circumstances that ... interfere with one's movement between two or more points." Thus impedance refers to a specific group of stressors (e.g., traffic congestion, traffic signals, intravehicular conditions) to which commuters are regularly exposed. Impedance is a form of behavioral constraint that specifically impedes the movement between two points. The greatest degree of impedance from traffic congestion would be experienced while travelling large distances slowly; the smallest degree of impedance would be experienced while travelling short distances quickly.

One hundred employees of two large industrial firms in Irvine, California were selected to participate in the initial study from a pool of over 300 volunteers, and these individuals were classified into groups based on the distance and duration of their daily commute. These measures were believed to be indicative of the amount of impedance encountered by each commuter. The subjects were classified into one of five groups based on the distance and duration of their daily commute. Those subjects whose commute fell within the bottom 25% of the distributions of distance and time were classified as low-impedance. This group consisted of 27 people who travelled less than 7.5 miles in less than 12.5 minutes on their way to and from work. Those subjects whose commute fell into the middle 30% of the time and distance distributions were classified as medium-impedance. There were 22 individuals who travelled between 10 and 14 miles in 17-20 minutes in this group. Those subjects whose commutes fell into the top 25% of the time and distance distributions were classified as high-impedance. There were 36 individuals in this group, and they travelled between 18 and 50 miles, spending 30 to 75 minutes on the commute.

The three groups discussed above were made up only of people whose commutes were consistent in terms of time and distance (i.e., if distance was high, time was high; if distance was medium, time was medium, etc.). Two additional groups were also formed. The first of these consisted of six people who travelled a short distance in a medium amount of time. The second consisted of nine individuals who travelled a medium distance in a long period of time.

The results of this study show that higher levels of impedance are associated with greater perception of traffic congestion as an inconvenience and lower levels of commuting satisfaction. High impedance subjects also rated themselves as more tense and nervous than did low impedance subjects.

These researchers found no main effect of the impedance variable on blood pressure when the analysis was confined to the three groups described above. However, correlational analyses of the entire sample show that distance, duration, and speed of the commute are all positively related with both systolic and diastolic blood pressure readings.

The ecological framework of this research emphasized that the effect of driving stress on individuals would not be uniform, but would interact with various individual difference variables. These researchers found an interaction between the Type A-B distinction and the impedance variable. The Type A-B distinction refers to a personality dimension: Type A individuals are very concerned with time related deadlines and tend to seem "driven;" Type B individuals are more relaxed and easygoing. Medium impedance Type A subjects had higher systolic blood pressure and greater performance deficits on a puzzle task than did Type B subjects. This pattern was reversed in the high impedance condition, and no differences were found in the low impedance group.

The subjects who participated in the initial study were contacted eighteen months later in an attempt to assess coping behaviors that had been used to deal with commuting stress, health changes, employment satisfaction, residential quality, and feelings about the commute. Eighty-two of the initial 100 subjects were contacted.

Among high impedance subjects who were contacted eighteen months after the primary phase of the study, 62% of those individuals who reported high satisfaction with their travel arrangements had made efforts to alter their commute (e.g., by joining carpools or substituting public transit or walking for automobile driving) while only 20% of the low satisfaction individuals had made such attempts. Among all subjects, those who had high scores on a summary coping index were more satisfied with their travel situation when contacted eighteen months after the initial study than they had been originally. The pattern was reversed for those subjects who had low scores on the coping index.

The follow up study also introduced a new twist to the concept of impedance. The initial time and distance defined measure was termed physical impedance. This was contrasted with a new measure of impedance, subjective impedance, which was generated from a large set of self-report items pertaining to perceived constraints in driving. Subjective impedance was found to be related to evening mood and reports of chest pain, but not with other health measures. Physical impedance was related to job satisfaction, illness-related work absences, and colds and flu. Commuting satisfaction, a subjective measure, was significantly related to job change.

Another group of researchers, Schaeffer, Street, Singer, and Baum (1988), has developed an alternative index of impedance as a measure of commuting stress, which is operationalized in terms of speed. In their study, subjects were divided into two groups, with those driving over 20 mph classified as low impedance and those driving under 20 mph classified as high impedance. Higher levels of impedance were associated with higher systolic and diastolic blood pressure and significantly poorer performance on a proofreading task. No differences were found on measures of heart rate and self-reported hostility or anxiety.

All of the drivers in this study were further classified into high and low control groups. Most stress research finds that individuals who can exert some degree of control over their environment are less susceptable to the effects of stress. In this study, carpool vs. single drivers was used as the primary measure of control, and the presence or absence of alternative commuting routes was used as a secondary measure. Within the high impedance group, low control (carpool) drivers showed significantly higher systolic blood pressure readings than did high control (single) drivers on all three days of the study. Being a carpool driver was positively correlated with diastolic blood pressure on days 2 and 3, and with higher heart rate on days 1 and 2. Single drivers were significantly more hostile and anxious after their commutes than were carpool drivers. Drivers who had a choice of commuting routes performed more poorly on behavioral tasks than did those who had only a single possible route to work. These results do not clearly indicate what effect control, as it is operationalized in this study, has on the experience of driving stress.

The results of these kinds of studies, then, indicate that driving does have a negative cumulative effect on the individual. Stress related physiological changes, health problems, unpleasant moods, performance deficits, and job dissatisfaction have all been shown to be related to the amount of stress in the individual's driving situation.

SUMMARY AND RECOMMENDATIONS

Stress is most usefully defined as a mismatch between an individual's perception of the demand present in a situation and that individual's perception of his or her own ability to cope with the demand. In the driving environment, stress is a function of the road and traffic environment and of the individual. The stress related to driving does not arise from a singular source; rather, a number of features of the driving situation can induce stress. Driving stress has immediate physiological effects and cumulative effects on health and psychological well-being. Research in this area has typically shown that:

(1) Immediate changes in heart rate, heart rate variability, electrocardiographic patterns, galvanic skin response, and urinary levels of catecholamines are associated with the driving situation. Individuals show considerably more physiological indicators of stress while driving than while resting. Road type, specific road elements (such as curves and on-ramps), the difficulty or complexity of the driving situation, and specific in-traffic maneuvers (such as passing, merging, being overtaken) have been shown to elicit higher levels of physiological stress in drivers. These stress responses are due primarily to increased attentional and decision making demands that such situations impose on the driver, and to the emotional responses that are evoked.

(2) Individuals differ greatly in their experience of driving stress. Not everyone shows the same patterns of physiological changes when confronted with a stressful situation. Not everyone finds a certain situation stressful. Some of these differences are specific to each unique individual, but other differences are systematic. For example, experienced and skilled drivers typically experience less stress in the driving situation than do less experienced drivers.

(3) The literature suggests that driving has cumulative effects on both the health and well-being of the individual. However, the extent and severity of these effects has not been well established. Only a few studies have been conducted in this area, and the data that they have generated are not sufficiently coherent to allow confident inferences about these effects to be made.

In light of the current state of empirical evidence on the topic of driving stress, several suggestions can be made as to specific areas of study that require clarification or elaboration. All of these recommendations involve verification of the assumptions and implications of the transactional model of driver stress.

Recommendations

1. Classification of driving situations in terms of their stress producing potential. Previous research on driving stress has employed small numbers of subjects (in many cases as few as six or eight drivers) to explore the impact of a single driving variable (e.g., being overtaken). Because of the use of small N, single variable designs, the literature consists of a number of isolated and often contradictory findings. The existing literature does not therefore provide a way to calibrate the relative stress producing potential of either roadway design variables or of traffic congestion variables.

Such calibration is essential for effective intervention. Transportation design and planning would benefit from more precise knowledge of both the situations that elicit stress, and their relative impact on different types of drivers. The transactional model of stress suggested above provides an appropriate guide for the execution of this research. The model requires that summary measures of the task demands posed by different driving situations be developed. For example, it requires quantification of the relative degree of difficulty between freeway driving and surface street driving. It requires quantification of the relative demands of congestion versus unimpeded driving. Such measures should be perceptually based and should quantify the difficulty of various driving tasks for different groups of drivers.

The transactional model also requires that the psychological and physiological impact of various driving situations be measured. This quantification of the relative stress producing properties of different driving tasks is conspicuously absent from existing literature. Current literature only suggests that some traffic events produce stress. Little is known about the <u>extent</u> or the <u>duration</u> of traffic induced stress. Virtually nothing is known about the impact of a given driving situation on different types of drivers.

2. <u>Exploration of the relationship between aging and driving stress</u>. The elderly are the fastest growing segment of society; almost 27 million people or 12% of the US population are over 65 today and the Census Bureau estimates that by the year 2020 almost 18% of the population will be elderly. The elderly are increasingly more likely to depend on the private car for their mobility; Rosenbloom (1988) has shown that the elderly took more trips in a private vehicle in 1983 than they did in 1977; over 91% of all trips in rural areas and over 87% of all urban trips by the elderly were taken in the private car. Further, analyses of long-term demographic trends indicate that by 2020 almost three quarters of the elderly will live in suburban or rural areas where alternatives to the car are non-existent.

Despite the importance of the subject, the relationship between aging and driving stress has yet to be empirically explored. The transactional model of stress indicates that perceived stress is a function of both external events and drivers' resources. The literature concerning the perceptual and cognitive consequences of aging (cf. Section II of this report) indicate that the information processing resources demanded by driving tend to deteriorate with advancing age. This suggests that as drivers age they should become more physiologically and psychologically stressed by traffic situations. This hypothesis, however, has yet to be empirically verified. Research in this area should attempt quantification of both the roadway design variables and the traffic situations that impose relatively greater stress on elderly drivers.

3. <u>Investigate the long-term cumulative impact of driving stress on both</u>

younger and older drivers. Because no longitudinal studies have been conducted, the hypothesis that driving stress leads to measurable changes in health is conjectural. Despite the evidence that driving is a stressor, and that stress negatively influences health, specific linkages between driving and health have rarely been documented. It therefore remains possible that driving produces a minimal long term impact on health. It is possible that people easily adapt to driving stress. It is possible that only a subset of the driving population is at risk. It is possible that the "cost" of traffic congestion and other traffic variables in terms of physical and psychological pathology is small. Without empirical study these and related questions cannot be answered. Large scale longitudinal studies are required that compare different groups (including the elderly) and different driving task demands while health is evaluated. Research should involve both prospective and retrospective research designs.

4. Explore the mechanisms that mediate the relationship between driving stress and health changes. Implicit in the concept of stress is that excessive stress, relative to an individual's capacities, induces illness. The support for this hypothesis comes from studies of the physiology of neuroendocrine systems and of the immune system (cf. Section III below). Research on driving stress requires research on both stress-health outcomes and on the mediators of those outcomes. To date, there exists fragmentary evidence that driving stress has an impact on cardiovascular health. No studies of immune system response to driving stress have been conducted. Further research on both of these topics is required if the relationship between driving stress and health is to be clarified.

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